# The EMPIRE JOURNAL of EXPERIMENTAL AGRICULTURE

VOLUME XXI

OXFORD
AT THE CLARENDON PRESS
LONDON: GEOFFREY CUMBERLEGE
1953

# EDITORIAL BOARD


SIR E. J. RUSSELL, Campsfield Wood, Woodstock, Oxfordshire (*Chairman*).
SIR G. F. CLAY, Colonial Office, Sanctuary Buildings, Great Smith Street, London, S.W. 1.
DR. E. M. CROWTHER, Rothamsted Experimental Station, Harpenden, Herts.
SIR F. L. ENGLEDOW, School of Agriculture, Cambridge.
DR. G. WATTS PADWICK, Imperial Chemical Industries, Ltd., Nobel House, 2 Buckingham Gate, London, S.W. 1.
SIR H. TEMPANY, 7 North End House, Fitzjames Avenue, London, W. 14.
SIR J. A. SCOTT WATSON, Ministry of Agriculture and Fisheries, Whitehall Place, London, S.W. 1.

(*The above constitute the Executive Committee*)

G. H. BACON, c/o Sudan Government Agency, 3 Cleveland Row, London, S.W. 1.
PROF. G. E. BLACKMAN, Dept. of Agriculture, Oxford.
W. V. BLEWETT, 197 High Street, Kensington, London, W. 8.
DR. E. E. CHEESMAN, Agricultural Research Council, 15 Regent Street, London, S.W. 1.
DR. D. P. CUTHBERTSON, Rowett Research Institute, Aberdeen.
DR. WILLIAM DAVIES, Grassland Research Station, Hurley, nr. Maidenhead, Berks.
DR. H. P. DONALD, Animal Breeding Research Organization, Edinburgh 9.
DR. T. EDEN, Tea Research Institute of East Africa, P.O. Box 91, Kericho, Kenya Colony.
DR. W. L. FIELDING, Gwebi Agricultural College, Salisbury, S. Rhodesia.
DR. T. D. HALL, African Explosives and Chemical Industries, Ltd., 40 Fox Street, Johannesburg.
DR. W. M. HAMILTON, Dept. Scientific and Industrial Research, New Zealand, Wellington, C. 1.
DR. J. HAMMOND, School of Agriculture, Cambridge.
DR. G. A. C. HERKLOTS, The Principal, Imperial College of Tropical Agriculture, Trinidad.
DR. E. S. HOPKINS, Central Experimental Farm, Ottawa, Canada.
DR. P. S. HUDSON, Commonwealth Bureau of Plant Breeding and Genetics, Cambridge.
DR. J. B. HUTCHINSON, Cotton Research Station, Namulonge, P.O. Box 884, Kampala, Uganda.
PROF. E. T. JONES, Welsh Plant Breeding Station, Aberystwyth.
G. V. JACKS, Commonwealth Bureau of Soil Science, Harpenden, Herts.
DR. H. D. KAY, National Institute for Research in Dairying, Shinfield, nr. Reading.
SIR B. A. KEEN, East African Agriculture and Forestry Research Organization, Box 21, Kikuyu, Kenya.
DR. A. H. LEWIS, Jealott's Hill Research Station, Bracknell, Berks.
DR. K. W. NEATBY, Dept. of Agriculture, Ottawa, Canada.
H. J. PAGE, c/o F.A.O., Rome.
DR. B. P. PAL, Indian Agricultural Research Institute, New Delhi.
DR. J. A. PRESCOTT, Waite Agricultural Research Institute, Glen Osmond, S. Australia.
DR. F. R. TUBBS, Horticultural Research Station, East Malling, Kent.
PROF. STEPHEN WATSON, Dept. of Agriculture, Edinburgh University.
DR. NORMAN C. WRIGHT, Ministry of Food, Dean Bradley House, Horseferry Road, London, S.W. 1.
DR. F. YATES, Rothamsted Experimental Station, Harpenden, Herts.

*Secretary and General Editor*

DR. H. L. RICHARDSON, c/o The Clarendon Press, Oxford.

# CONTENTS

## *Number 81*

H. C. Pereira and V. R. S. Beckley: Grass Establishment on Eroded Soil in a Semi-arid African Reserve. With Plate 1. 1

E. S. E. Hafez: Conception-rate and Periodicity in the Buffalo 15

M. H. R. Soper: The Influence of Farm Practice on the Productivity of Field Beans . . . . . 22

M. S. Motta: *Panicum maximum* . . . . . 33

G. L. Bailey, M. E. Castle, and A. S. Foot: Fodder-beet. Part III. Feeding Trials with Dairy Cattle . . . . 42

F. C. O. Speyer: Reflections on the World Nitrogen Position 49

P. Mahadevan: The General Life and Production Statistics of the Sinhala Cattle of Ceylon . . . . . 55

L. Koncar and I. Smalcelj: The Wool Fineness and Percentage of Medullated Fibres in Wool of Lambs 1–6 months old 61

## *Number 82*

H. Vine: Experiments on the Maintenance of Soil Fertility at Ibadan, Nigeria . . . . . 65

J. J. Theron and D. G. Haylett: The Regeneration of Soil Humus under a Grass Ley . . . . . 86

T. M. Carey and P. Robinson: The Manuring of Sugar-cane 99

W. E. J. Milton: The Palatability of Herbage on Undeveloped Grasslands in West-central Wales . . . . . 116

H. G. Mundy: Some Problems of Arable Farming in Southern Rhodesia . . . . . 123

D. H. Constable and G. E. Hodnett: The Manuring of *Hevea brasiliensis* at Dartonfield, Ceylon . . . . . 131

T. M. W. Davidson and D. N. Lawley: Experimental Evidence of Clonal Variation affecting Yield in Potatoes. . 137

P. O. Wiehe and W. J. Dowson: A Bacterial Disease of Cassava (*Manihot utilissima*) in Nyasaland. With Plate 2 . 141

A 45113

## *Number 83*


T. A. RUSSELL: The Spacing of Nigerian Cacao . . . 145

J. C. BONSMA with J. VAN MARLE and J. H. HOFMEYR: Climatological Research on Animal Husbandry and its Significance in the Development of Beef-Cattle Production in Colonial Territories. With Plates 3–7 . . . . . 154

P. H. NYE: A Survey of the Value of Fertilizers to the Food-Farming Areas of the Gold Coast. Part I. Aims and Methods of the Survey . . . . . 176

F. M. L. SHEFFIELD: Virus Diseases of Sweet Potato in Parts of Africa . . . . . 184

C. BARCLAY: A Self-Cleaning, Miniature Thresher . . 190

J. R. BARROWMAN, T. G. BOAZ, and K. G. TOWERS: Castration of Lambs: Comparison of the Rubber-Ring Ligature and Crushing Techniques. With Plates 8, 9 . . . . . 193

G. E. HODNETT: The Responses of Sugar-Cane to Fertilizers in Trinidad . . . . . 204

E. S. E. HAFEZ: Puberty in Female Farm Animals . . 217

I. A. S. GIBSON and P. K. S. CLINTON: Pre-Emergence Seed-bed Losses in Groundnuts at Urambo, Tanganyika Territory . . . . . 226

R. W. SHEPHERD: The Mechanical Thinning of Sugar-beet . 236


## *Number 84*


J. L. BOLTON and M. W. CORMACK: Breeding Alfalfa in Canada 241

C. R. W. SPEDDING: The Effect of a Sub-clinical Worm-burden on the Liveweight Gain of Lambs . . . . . 255

P. H. NYE: A Survey of the Value of Fertilizers to the Food-Farming Areas of the Gold Coast. Part II. The Granitic Soils of the Far North . . . . . 262

K. L. ROBINSON, W. E. COEY, and G. S. BURNETT: The Response of Pigs to Dietary Procaine Penicillin . . . 275

GEORG F. HAUSER: Sugar-beet Cultivation in Afghanistan and its Improvement . . . . . 283

L. B. THOMSON: The P.F.R.A. and a New Prairie Agriculture. With Plate 10 . . . . . 289

H. K. PANDE: Effect of Weeding on the Yield of Wheat . 297

M. T. RAGAB, A. A. ASKER, and M. R. KADI: Genetic Factors affecting Weights of Ossimi Lambs . . . . . 304

E. R. HATTINGH: Observations on the Ecology of *Stoebe vulgaris* Levyns. With Plate 11 . . . . . 309

A. T. PUGSLEY: Back-crossing of Wheat for Resistance to Bunt in South Australia. With Plate 12 . . . . . 314

DON R. ARTHUR: Recent Developments in Tick Control in Britain . . . . . 321

K. WILSON JONES: Further Experiments on Witchweed Control. I. The Effect of Hormone Weed-killer Applications at Different Rates and Times on Irrigated Dura . . . . 331

J. A. R. MACLEAN: Some Chemical Aspects of 'Black-Pod' Disease in West African Amelonado Cacao . . . . 340

Indexes . . . . . 350

# GRASS ESTABLISHMENT ON ERODED SOIL IN A SEMI-ARID AFRICAN RESERVE

H. C. PEREIRA[1] AND V. R. S. BECKLEY[2]

WITH PLATE I

*Summary.*—AN area typical of bare overgrazed land in the semi-arid Machakos African Land Unit has been used for experiments on restoration of fertility and on land management. A 32-acre factorial experiment on methods of grass establishment is described. Sown and planted grasses were tested on land prepared by various cultivation treatments, and the first two years of grazing-yields are reported. Yields were substantially improved by ploughing, by manuring, and by the incorporation of manure in ridges. Ripping did not improve grass establishment or soil-moisture storage. In two drought years, 10·13 and 16·71 in. of rain respectively, the planting of grasses was more successful than sowing. In a year of very good rainfall sown grasses were rapidly established, and gave yields equal to those of the planted species. Ridging was found to conserve available soil moisture for two months of dry weather. Grass roots increased the field capacity of the first 3 in. of soil, but did not, in 2 years, increase the volume of free-draining pore-space.

## *The Problems*

The widespread and spectacular soil erosion in the Ukamba Reserve near Machakos in Kenya has frequently been described, e.g. by The East African Commission [1], Beckley [2], The Carter Land Commission [3], and by Maher [4, 5]. Continuous overstocking and overcultivation by a pastoral people unskilled in agriculture, together with alternation of severe droughts and brief torrential rains, have caused the type of soil deterioration found in India and in other parts of Africa.

The inhabited, tsetse-fly-free part of Machakos District consists of a much dissected peneplain draining to the East and ranging in altitude from 4,000 ft. to 5,000 ft. From these irregular lowlands several hill masses rise steeply to heights of 6,500 to 7,000 ft. The lowland soil is a red sandy loam derived from the weathering *in situ* of gneisses and schists of the basement complex, supplemented by soil washed from surrounding hills of the same parent materials. Rainfall throughout the lowland area is substantially less than that of the nearest long-term records. These are for Machakos township, some 5 miles from the experiments; here the average annual rainfall, recorded over 56 years, is 36 in. The annual total has varied from 15 to 62 in., distributed in two brief rainy seasons. In the dry weather hot winds from the arid plains to the south-east are very severe. The natural vegetation of this part of the lowlands is tall grass with scattered acacia thorn-trees. *Themeda*

[1] Soil Physicist, East African Agric. and Forestry Research Organization, formerly Coffee Research Team, Kenya Dept. of Agriculture.

[2] Agricultural Officer (Expts.), Kenya Dept. of Agriculture.

[Empire Journ. of Exper. Agric., Vol. 21, No. 81, 1952.]

*triandra*, *Panicum maximum*, and *Cenchrus ciliaris* are probably the most common of the very numerous grass species that occur.

When the first European travellers passed through this area in the 1880's, the Wakamba lived mainly in the hills, for fear of the raiding Masai. With the arrival of the Imperial British East Africa Company in 1894, this fear was removed, and the people began to spread into the lowlands. In spite of a severe drought and famine in 1899, in which many thousands of stock died, the Wakamba continued to accumulate vast herds of cattle, sheep, and goats, which steadily destroyed the natural vegetation. In 1910, within 16 years of the coming of Pax Britannica, the District Commissioner stated in his annual report that grazing was non-existent in many parts of this African Reserve. He allowed 19,000 cattle and many thousands of sheep and goats to move to the nearby Yatta Plateau, which was then unoccupied. This gave no effective relief to the Machakos area, and in every subsequent year grazing was reported as being short. The estimated stock population rose in 1937 to 350,000 cattle, 269,000 goats, and 50,000 sheep, which was equivalent to one cow and one sheep or goat to every 3 or 4 acres, including all arable land and hill-top forests, and in a district where 1 acre in 4 was then reported to be almost completely devoid of vegetation [4]. Restoration by administrative closing of grazing areas was tried as early as 1919, but even after several years of such closure the vegetation consists mainly of acacia thorn-scrub and ephemeral annual grasses of the aristida type. Intermittent illicit night-grazing by sheep and goats, and lack of co-operation from the people, have repeatedly defeated such attempts at closure.

Whilst the basic problems are those of social organization, to bring the community into harmony with its natural environment, the Administration has been greatly handicapped by lack of factual information on the technical solutions, first to the problem of re-establishment of a productive grass-cover on eroded land, and secondly, to the problems of intensive management of small holdings under very variable and unreliable rainfall.

*The potential carrying capacity for cattle.*—When both people and stock are distributed in the present tribal system of fragmented holdings and uncontrolled grazing, the optimum densities of families and cattle are impossible to determine. The experiments described here are a first stage in the direct assessment of the potential carrying capacity of these areas under improved systems of management. Valuable direct evidence of this carrying capacity is available from the ranches of neighbouring European settlers, where Wakamba labourers with their families and cattle are organized for rotational grazing on a communal basis. Here, under the control of some of Kenya's British pioneers, large human and animal populations have been maintained for 30 years or more. Protection of soil and herbage has been increasingly effective as experience has been gained, whilst there has been a steady improvement in water-supply by construction of dams.

On one such ranch, immediately bordering the African lands, an area of 5,600 acres (about 9 sq. miles) is permanently allocated to the Wakamba

labour force. Some 600 acres of terraced arable are devoted to food crops, which support a population totalling 1,350 of all ages. The remaining 5,000 acres carry approximately 660 cattle, by a system of strictly controlled rotational grazing, operated by the elders of the group under vigilant European supervision. Water is provided by several small dams. The densities are thus 150 people to the square mile, with $7\frac{1}{2}$ acres of grazing per beast. In drought years, although the grazing is adequate, grain from the rest of the farm is supplied to meet about one-third of the human food requirements. The 600 acres of arable supply the remaining two-thirds, so that 900 acres would be required, in drought years, to feed the 1,350 people. This represents two-thirds of an acre of crops per head of population. In the adjoining Machakos reserve, the overall density of population is only a little higher, at about 166 per sq. mile, but the larger number of beasts, kept for traditional reasons, reduces the grazing area to 3 or 4 acres per beast. In addition, the lack of agricultural skill and discipline results in severe loss of efficiency in land utilization, so that the denuded and eroded countryside offers a painful contrast to these well-managed lands.

### *The Experiments*

The united efforts of the District Team succeeded in 1948 in persuading the Machakos African District Council to arrange the temporary evacuation of 150 acres of badly overgrazed and eroded land in the Makaveti area. This area lies in the middle of the peneplain described above, at an altitude of 4,900 ft. The land was handed over to the Agricultural Department for study and experiment on restoration methods, for an initial period of 5 years. One recalcitrant plot-owner refused to move and was allowed to remain under strict supervision. The area included broad low ridges covered with scattered thorn-scrub, gulleyed slopes and deeply eroded dry flood-channels. The soil when reconnoitred by auger showed an interesting profile. More than 80 per cent. of the surface-area appeared to be either a loose red dust or a very hard, red shield of baked soil with few cracks. The shield was very thin, about $\frac{1}{2}$ in. or less, and had been rendered almost impervious by the beating of intensive rains and the continuous treading by hooves of cattle and goats (Plate 1, a). Beneath this crust the soil structure was unexpectedly good, and traces of dead grass-roots were abundant in the first foot. Pits revealed a depth of 4 to 5 ft. of red sandy loam over decomposed parent rock. There was a noticeable effect of wind, the bare soil being very hard and dry to 4 in. or more on the windward slopes, but having more moisture near to the surface on the leeward slopes. The depth of the consolidated crust was similar for both slopes.

The 150 acres were fenced, and patrolled by guards to prevent illicit grazing, whilst gulley erosion was checked by pegged brushwood wash-stops and some hand-dug contour ditches. The steeper slopes were completely stabilized by narrow-based terraces. Thus protected from fire, grazing, and cultivation, the initial recovery of indigenous grasses was encouraging. Recovery was especially good along the lines of old terraces which had been built by the Agricultural Department some 20

years previously, but abandoned by the cultivators. It was clear, however, that some years of such active and expensive protection would be required for the natural restoration of this land to a level of agricultural efficiency. Direct methods of restoration were studied concurrently by mechanical cultivation on the contour, followed by the sowing or planting of grasses.

Much of the information was expected to be observational, but in an area of varying topography, and on soils with varied plot histories, it is essential that observations be both replicated and randomized. Plots of very large size were used to permit study of grazing management under semi-arid conditions and the assessment by grazing of the value of the grass species and methods of establishment. Thirty-two plots of 1 acre were therefore laid out, on the contour, as a $4 \times 2 \times 2 \times 2$ design in four blocks. For observation of the effects of the prevailing hot dry SE. winds, two blocks were sited on tops of ridges, the third on a windward slope, and the fourth on a leeward slope. The simplest or 'control' treatment was the breaking of the soil surface-crust by a rigid-tine cultivator, which penetrated from 1 to 3 in., according to surface conditions. This was compared with the following treatments, in factorial combination:

*A*. Contour ploughing to a depth of 6 in.

*B*. Contour-ridging with a 3-furrow tractor-mounted potato-ridging equipment.

*C*. Addition of dry cattle manure at 10 tons per acre.

Although the dressing is small it represents the maximum cattle dung obtainable from the resources of the area. Testing of larger dressings would therefore have had a less direct bearing on the problem, and the inclusion of different levels would have unduly complicated the experiment. The manure was ploughed in, scarified into the loose soil, or applied under split ridges, as the treatment combinations required. Of the four grass species tested, two were sown and two planted. The species selected on the advice of the local Agricultural Officer were, for planting, *Panicum coloratum* var. *Makarikariensis* and *Cynodon dactylon* (Star grass). The sown grasses were *Eragrostis curvula* and the Trans Nzoia strain of *Chloris gayana* (Rhodes grass), the latter sown with a nurse-crop of perennial sorghum. An additional treatment (added by Departmental instructions while the field cultivations were in progress) consisted in deep ripping with a Le Tourneau ripper pulled by a tracklayer. All plots were split longitudinally, and one-half of each plot selected at random was therefore ripped on the contour.

## *Observations*

(*a*) *Cultivation methods.*—Cultivations were begun in dry weather in March 1949 in preparation for the 'long' rains. Ploughing was effective to 6 in.; it involved the undesirable result of exposing soil in good structural condition, formerly protected by the erosion crust, to the disintegrating effects of sun and rain. Only a light wheeled-tractor was

available with a very light mounted tine-cultivator. This proved rather inadequate for the task, especially where ridging was to follow. Where the tine-cultivation was completed in one operation, a very favourable cloddy tilth was obtained, exposing little of the better soil to weathering. The ripper had three tines 2 ft. apart, and penetrated from 10 to 18 in. The potato-ridging equipment produced satisfactory ridges 2 ft. apart and 9 in. high; splitting these over the cattle manure scattered in the furrow proved difficult with the light tractor. The rains failed almost completely, only 5 in. being received during the experiment, much of it

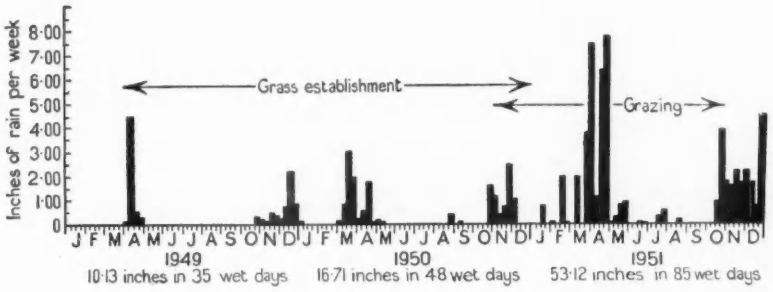



FIG. 1.

in three heavy falls. It was found possible to plant and sow only two blocks, or half of what was intended. A long and severe drought followed (Fig. 1).

(*b*) *Grass-establishment estimates.*—A thin and irregular stand of sorghum was obtained, but both the sown grasses failed completely. Germination was poor and less than 1 per cent. cover resulted. In contrast, the planted grasses showed remarkable powers of drought-resistance. The beneficial effect of contoured ridging was very noticeable: the grass 'splits', planted into the uphill sides of the ridges, developed roots in the moist soil under protection of the ridge. In mid-August 1949, after 3 months of drought, a detailed count of the surviving grass splits was attempted but had to be abandoned through shortage of staff, so that the incomplete set of results permit a balanced comparison only for the effect of ripping. Individual splits in sample strips of five rows were recorded by visual estimate as alive or dead, and the percentage survival was calculated for each strip. Table 1 gives totals for all plants counted.

The percentage survival rates on the seventy-two sample strips, analysed after angular transformation, show a significant average depression due to deep ripping. This depression was very significant for the Panicum but did not reach significance for the Cynodon, where it was partly masked by the beneficial effects of ridging.

The short rains from October to December again failed, only 5·13 in. being received. In the very few days available for sowing and planting, it was only possible to resow the existing plots with the *Chloris gayana*

TABLE 1. *Survival Rates of Plants on Unripped and Ripped Soil*

| | *Panicum* (*Makarikari*) | | | *Cynodon* (*Star*) | | |
|---|---|---|---|---|---|---|
| | *Planted* | *Survived* | *Survival %* | *Planted* | *Survived* | *Survival %* |
| Unripped . . | 4,892 | 838 | 17·2 | 1,162 | 241 | 20·8 |
| Ripped . . | 3,616 | 233 | 6·5 | 1,122 | 196 | 17·5 |
| Least significant differences . | .. | .. | (P·01) 4·7 | .. | .. | (P·05) 5·9 |

and *Eragrostis curvula*, and to refill the gaps in the two planted grasses. The planting material available was very poor and drought-stunted. A further 3 months without rain followed. Plot-observation notes record that the Cynodon, although very drought-resistant and developing long runners, provided soil protection very slowly. The Panicum developed large tufts, tending to remain isolated, but these covered enough of the ground to provide some protection. A few patches of Rhodes grass which had become established showed promising growth, so that this species was sown for the third time in April 1950. The *Eragrostis curvula* failed again, partly through poor germination, but mainly through lack of drought-resistance at the seedling stage.

In the 'long rains' of 1950 in March and April only 8·68 in. of rain fell. It was, however, possible to complete the planting of the experiment as well as to fill the gaps in the existing plots. The previous season had shown very careful planting of the Panicum and Cynodon to be essential. In 1950 this produced an almost complete 'take' of these grasses, and before the following dry season the new plantings had become established and had made some growth. The older plantings made sufficient growth for one of the plots of Panicum to be grazed for 8 hours by 10 cows. The new sowing of Rhodes grass failed, due partly to the competition from the sorghum and partly to the poor rains. In those plots where the Rhodes grass was already established and where the sorghum had been suppressed the new seedlings did better and a fair stand was obtained by the beginning of the October rains. The *Eragrostis curvula* failed yet again and was replaced by a mixture of local grasses. It had been noticed that the headlands and spaces between the plots had become covered with a considerable growth of indigenous grasses of which *Cenchrus ciliaris*, *Eragrostis superba*, and *Bothriochloa insculpta* were the most promising. Seed of the first two was collected and was sown to replace the *Eragrostis curvula* in the October rains of 1950. Gaps in existing plots were filled and Rhodes grass was sown where necessary. During these rains 7·38 in. fell and great progress was made. All the plots were at last, after 2 years, covered with grass (Plate 1, b).

By November 1950, in the middle of the short rains, ten of the 1-acre plots sown in 1949 had achieved a sufficient grass cover to permit controlled grazing. Two of these plots were under Rhodes grass, four were under Makarikari grass, and four were under Star grass. Grazing began in mid-November, and continued for 3 or 4 weeks ceasing as each plot reached a similar condition. This left a further 3 weeks of good growing-

conditions to follow, so that all plots entered the dry season with some cover. Adult native cattle were used in groups of from 15 to 40 beasts. Beast-hours were recorded, and the total for each plot was divided by eight to give 'beast-days per acre' as a standard measure of grazing yield.

*Results.*—Beast-days per acre: Rhodes grass 62; Makarikari grass 43; Star grass 21.

In addition, three of the plots re-established in 1950 had progressed sufficiently for some grazing. These gave:

Rhodes grass 17; Makarikari grass 11; and Star grass 3½ beast-days per acre.

The differences, in these early stages of establishment, were large and consistent. The effect of the grazing differed with the grass species. Whilst early grazing had little effect on the spread of Star grass, the cattle showed a marked preference for the new lateral shoots of the Makarikari grass, and this pruning greatly retarded its lateral spread.

By the end of 1950 the Cynodon, Panicum, and Chloris were satisfactorily established, and the last-named was beginning to send out runners. The local *Cenchrus ciliaris* and *Eragrostis superba* produced a fair cover, despite their low germination (of 12·6 per cent. and 0·82 per cent. respectively). Some rough hand-weeding was occasionally required, together with the continuous removal of thorn-scrub as this appeared. Almost pure stands of the grasses under test were ultimately obtained, although some *Digitaria abyssinica* invaded a few plots.

Effects of ridging were noticeably beneficial, the ridged plots remaining green throughout the particularly hot dry season.

The experiment entered its third year in March 1951 with an almost 100 per cent. survival of both planted grasses, and with an establishment of both species of sown grasses sufficient to develop without further sowing. Cover on all plots was still incomplete, but valuable protection against erosion was attained. An assessment of the degree of establishment of the four grasses was therefore attempted. Trained staff could not be spared to make the number of random quadrat counts required for so large an area, and the individual plots were not sufficiently uniform to permit scoring by eye. Two test-strips were therefore sited by a trained observer in the good and the poor cover respectively, and an estimate made of the proportion of the plot represented by each. The number of 10 × 10 cm. divisions in a metre-square frame in which grass occurred, were counted as the frame was moved along the strips. The two strip counts were then weighted and combined to give an estimate, for each whole plot, of the proportion of the surface area on which grass occurred (Table 2).

The above results for percentage cover appear very low, but to the eye the plots appeared to be fairly well grassed, the height of the grass effectively concealing its open spacing. Protection of the soil surface from sun, rain, and wind was greater than that indicated by the surface-cover. These measurements are, however, useful as estimates of the effects of treatments. The cattle dung had increased by about one-quarter the area of established grass. The Star grass had reacted favourably to the preliminary grazing, and had spread better than the

Makarikari, whilst the cultivation methods, at this stage, showed surprisingly small differences.

TABLE 2. *Grass Cover after Two Dry Years*

| | *Cover* % | *Differences* % | *Statistical reliability* |
|---|---|---|---|
| *Species* | | | |
| Star grass | 26·9 | 5·9 | P·05 |
| Makarikari grass | 21·0 | 8·8 | P·01 |
| Rhodes grass | 12·2 | 1·2 | N.S. |
| Local grasses* | 11·0 | | |
| *Cultivation methods* | *Flat* *Ridged* | | |
| Scarified | 17·5 15·0 | .. | |
| Ploughed | 17·7 17·3 | .. | N.S. |
| *Cattle dung at 10 tons/acre* | | | |
| With dung | 19·6 | 3·7 | P·05 |
| No dung | 15·9 | | |

* 25 per cent. *Cenchrus ciliaris* and 75 per cent. *Eragrostis superba*, at first sowing.

*Rotational grazing of paddocks.*—The most effective test of the degree of establishment of grass on each plot was considered to be its carrying capacity under intensive rotational grazing. Each 1-acre plot was therefore fenced. Division into two ½-acre paddocks permitted easier control of grazing intensity and provided sub-plots for subsequent trials of grazing management. Small groups of adult native cattle, usually containing from 10 to 15 beasts, grazed each ½-acre paddock on successive days until the grass reached an eye-estimated 'short' condition, before moving on to the next paddock. Four groups, each in charge of a herd-boy, were employed concurrently. It was interesting to note the reaction of the local Wakamba at this stage. Whereas they had previously shown little or no interest in the area, or even in the idea of planting pasture grasses, the sight of their own cattle on grazing which appeared luxuriant by comparison with the surrounding countryside attracted numerous spectators. Beasts for the grazing experiments were readily supplied by the owners of the land on agreed conditions of absolute control by the Agricultural Officer. This grazing was continued for 25 weeks, from April to October. As before, the detailed records of beast-hours were divided by eight and expressed as standard 'beast-days per acre'. The mean yield was 183·6 beast-days per acre, equivalent to an average carrying capacity of almost exactly one beast per acre for the 6 months. Individual plots varied between capacities of one-third and 2½ beasts per acre. At this stage the establishment studies were considered to be concluded, although long-term effects would be measurable in subsequent experiments. The results were therefore analysed (Tables 3, 4, 5), and new schedules of grazing and resting treatments began with the short rains in October 1951. For the year, grazing of 6 months' duration was obtained at an average rate of one beast per acre.

TABLE 3. *Carrying Capacity in Beast-days per Acre*

| *Totals for grass species* | | | | |
|---|---|---|---|---|
| *Planted grasses* | | *Sown grasses* | | |
| *Makarikari grass* | *Star grass* | *Rhodes grass* | *Cenchrus ciliaris** | *Least sig. diff. at P·05* |
| 1,707 | 1,624 | 1,410 | 1,100 | 422 |
| 3,331 | | 2,510 | | 597 |

* The plots sown with local grasses now carry mainly *Cenchrus ciliaris*.

The heavy extra labour expended on planting grasses as compared with sowing them, was thus rewarded both by a little grazing in the drought conditions of 1950, and by a one-third increase of the carrying capacity in the subsequent high rainfall year of 1951.

TABLE 4. *Effects of Ridging and Ploughing*

| | *Makarikari grass* | *Star grass* | *Rhodes grass* | *Cenchrus ciliaris* | *Totals* |
|---|---|---|---|---|---|
| Ridged . . . | 915 | 857 | 728 | 613 | 3,113 |
| Flat . . . . | 792 | 767 | 682 | 487 | 2,728 |
| Differences . . | 123 | 90 | 46 | 126 | 385 |
| Increase per cent. . | 16 | 12 | 7 | 26 | 14 |
| Ploughed . . . | 1,012 | 966 | 743 | 697 | 3,418 |
| Scarified . . . | 695 | 658 | 667 | 403 | 2,423 |
| Differences . . | 317 | 308 | 76 | 294 | 995 |
| Increase per cent. . | 46 | 47 | 11 | 73 | 41 |
| Least sig. diff. at P = ·05 . . | | 298 | | | 579 |

The ridging showed a consistent beneficial trend which did not reach the 5 per cent. level of significance.

The effects of preparing land by the plough, as compared with breaking the crust, are most striking at this stage. Rhodes grass showed no effective benefit, but the remaining three grasses yielded substantially more grazing on the ploughed plots.

No significant differences were established between the separate responses of the four grass species to cattle dung, but all responses were positive, and over the whole experiment a very highly significant increase of 57·5 per cent. in grazing yields was obtained. Ploughing and scarifying gave equal responses to dung: a rather unexpected result. Ridging, however, gave a positive interaction at the one per cent. level of significance.

TABLE 5. *Responses to Dung*

| | *Flat* | *Ridged* | *Sig. diff.* |
|---|---|---|---|
| No dung | 1,273 | 995 | 422 at P·05 |
| Dung | 1,455 | 2,118 | 601 at P·01 |

The three-factor interaction did not reach significance, but the most thoroughly prepared areas, ploughed, dunged and ridged, gave the highest grazing figures.

*Effects of ridging and of ripping on the conservation of soil moisture.*—In the severe drought of 1949, soil-moisture conditions were tested when the period without effective rain had extended to 66 and 180 days respectively. On the 66th day of drought, soil-moisture distribution on a ploughed and ridged area was sampled to observe effects of ridging and ripping. Fig. 2 gives the mean values of three replicate sets of samples (moisture as per cent. of weight of oven-dry soil).

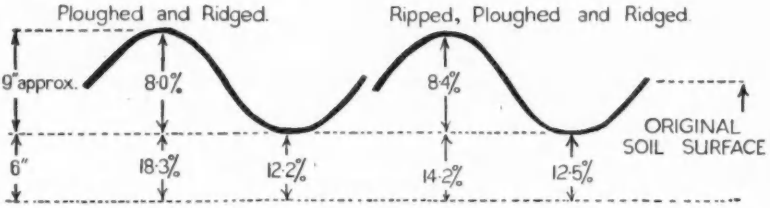



FIG. 2. Soil moisture conditions after 66 days without rain.

Least significant differences (by angular transformation) { P·05 . . . 3·2 per cent. P·01 . . . 4·4 per cent.

Wilting-points, determined by sunflower seedlings in the laboratory for the 0–3 in. topsoil, gave a consistent mean value of 13·6 per cent. (S.E. of mean ±0·17).

The number of samples taken was sufficient to show consistent and significant differences between the levels of soil moisture conserved under the ridges. The ripping appeared to have dried out the soil. In a well-drained sandy loam under intense sunshine this effect is not surprising.

After 180 days of continuous drought, soil-moisture sampling was repeated, this time comparing ploughed land ± ripping ± ridging. The

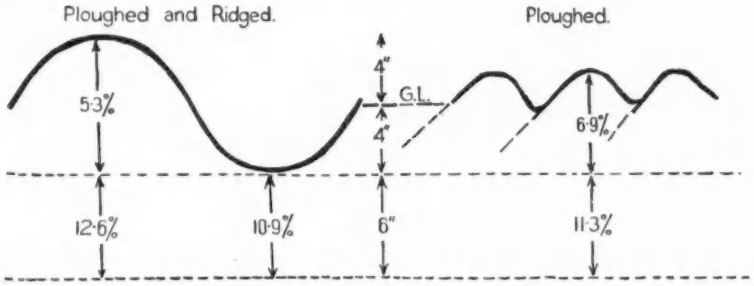



FIG. 3. Soil moisture conditions after 180 days without rain.

Least sig. diff. at P·05 1·9 per cent., at P·01 2·2 per cent.
Wilting-point (0–3 in.): 13·6 per cent. ±0·17 per cent.

soil was now much drier and the moisture-contents were more variable; no significant differences were obtained, apart from the obvious effects of depth of sampling. Fig. 3 shows the result of six replicate sets of samples to the depth critical for survival of the drought-stunted grasses.

Thus the available water detected under ridges after 66 days of drought had been lost by the 180th day. The ability of the four species of grasses to withstand long spells of drought was therefore severely tested.

*Soil-structure estimates.*—Soil changes were reconnoitred by volumetric sampling, a dozen undisturbed cores being taken on each of three pairs of soil conditions. These metal-sleeved cores were 4 in. diameter and 3 in. high. They were taken from the surface-soil, vacuum-wetted, drained in stages on a tension table, tested for percolation rate under a 1 cm. head, and the real volume of soil particles was determined. The most important measurements were considered to be those of the free-draining pore-space, through which air and water move. These measurements give the real 'structure' of the soil, and avoid the arbitrary assumptions involved in crumb-size measurements.

TABLE 6. *Effects of a 3-inch Cultivation followed by 5 inches of Rain*

| | *Free-draining pore-space as % of apparent soil volume* | |
|---|---|---|
| | *At 50 cm. tension* % | *At 100 cm. tension* % |
| Undisturbed soil . . . | 13·2 | 16·9 |
| Soil scarified 3 in. deep . . | 10·3 | 14·9 |

The differences, which reach only the 5 per cent. level of significance, suggest that although the surface-crust was cracked by the cultivation, the effect of rain on the disturbed soil was to decrease the useful structure of the first 3 inches.

TABLE 7. *Effects of the First Year of partial Rhodes Grass Cover*

| | *Field-moisture content* % | *Percolation under 1 cm. head* | *Free-draining pore-space at 50 cm. tension* % |
|---|---|---|---|
| Rhodes grass | 8·3 | 5·4 in. per hour | 10·4 |
| Bare soil | 3·9 | 2·8 in. per hour | 10·6 |

The grass was still in clumps, separated by 3 to 6 in. of bare soil, when sampled on January 30, 1951. Cores were taken in these spaces between clumps, and on nearby uncultivated soil.

The protection of the soil-surface from sun and wind by the Rhodes grass had preserved more moisture in the surface 3 in., although even between grass clumps the soil moisture was well below permanent

wilting-point (13·6 per cent.). The volume of large pores drained at 50 cm. tension remained unchanged, the root-channels, at this early stage, remaining full of live roots. An unexpected increase in percolation rates was caused by the activities of harvester ants, which had substantially reduced the stands of seeded grasses. Numerous fine vertical holes traversed each 3-in. core, making a negligible contribution to pore-space but, by their continuity, causing a large increase in percolation rate. This well illustrates the effects of increased biological activity associated with the restoration of vegetative cover to a bare soil.

*Effects of two years of a partial cover of Rhodes grass.*—Cores taken near the end of the second year of grass establishment, again on bare soil between adjacent grass clumps, showed a progressive increase in total pore-space, although the free-draining pore-space remained unchanged at approximately 10 per cent. of the volume. The increase was due to the growing volume of roots, the change in field capacity, estimated as water retained by the soil cores against a tension of 50 cm., being significant at the 5 per cent. level.

TABLE 8. *Field Capacity Changes*

| | *Bare soil* % | *First-year grass* % | *Second-year grass* % |
|---|---|---|---|
| Air . | 10·6 | 10·4 | 9·5 |
| Water . | 35·0 | 38·3 | 42·0 |
| Solids . | 54·4 | 51·3 | 48·5 |

These tests will be continued, but the initial measurements suggest that grass leys in this area will require several years to achieve any substantial improvement in soil structure.

*Labour expended in planting and sowing.*—This work was done by communal labour groups, consisting largely of women. These groups were far less effective than the equivalent number of regular farm labour, but any large-scale restoration of these African lands must be carried out by communal action, and the data are therefore relevant. All the operations were recorded, but the very great variations render the following estimates extremely approximate.

TABLE 9. *Labour spent on Planting and Sowing*

*Approx. Man-hours per acre*

| | |
|---|---|
| Hand-sowing in shallow drills | 30 |
| Broadcasting | 2 |
| Planting grass 'splits' | |
| Preparation of material | 40 |
| Holes, made by digging stick | 150 |
| (or) Holes, made by jembe (hoe) | (40) |
| Planting | 100 to 300 |
| Total operation | 200 to 500 hrs. |

The hours are those spent on the task by gangs under African supervision. European supervision halved the time spent per acre, and, by ensuring more thorough planting, greatly increased the survival rate of the planted grasses.

### *Supplementary Observations and Future Treatments*

Concurrently with the trials reported above, the responses of volunteer grasses to both cultivation and fertilizer treatments were tested on some smaller plots. Even in the first dry year, breaking of the surface-crust gave some improvement, but in the good rainfall of 1951 the cultivations alone gave striking improvements. Scarifying gave about twice, and ridging about four times the amount of cover that volunteered on the untreated areas.

Other plots were scarified and given broadcast dressings of $\frac{3}{4}$ cwt. per acre of sulphate of ammonia and 2 cwt. per acre of single superphosphate, in the combinations nil, n, p, np. By eye-estimate the effects of these dressings on the volunteer herbage were negligible. Fertilizers may well effect the persistence of swards, and this will be tested by further grazing trials, both on the established grass plots and on paddocks of volunteer herbage. These trials will test productivity and persistence under intensive rotational grazing, using modern agricultural methods, and also under the type of rotation available to the African smallholder.

### *Conclusions*

A typical bare overgrazed area of the Machakos African Land Unit has been restored by sound agricultural practices to pastures of high carrying-capacity. The barren and eroded conditions resulting from the destruction of vegetation have not yet caused irrevocable loss of soil fertility. When rainfall absorption is re-established by the breaking of the erosion-crust and the restoration of a herbage cover, the growth and yield of pasture grasses are unexpectedly good. The best grazing yields followed contour ploughing and ridging, with incorporation of a small dressing of cattle manure in split ridges. Deep ripping did not assist in grass establishment under the low rainfall conditions tested. Effective cover was obtained with all four grass species in two years in which 10·13 and 16·71 in. of rain fell in 35 and 48 days respectively.

The two sown grasses, *Chloris gayana* and *Cenchrus ciliaris* appear equally useful at this stage, and mixtures of grasses with the numerous local indigenous legumes will probably give the best results. *Eragrostis curvula* failed conclusively and is insufficiently drought-resistant for this area. Of the two species planted, neither showed any significant advantage in carrying capacity, but the Cynodon was spread by grazing, whilst the Panicum was pruned to isolated tufts. From the experience so far gained, the Cynodon is the more suitable planted grass for this area. Although the planting involves a very heavy labour demand, it greatly reduces the risks of total failure in a dry year. In view of the extreme variability of annual rainfall, the policy recommended by the authors is a rapid sowing at the beginning of the rains, followed by the planting of

wash-stop contour strips of Cynodon throughout the duration of planting weather.

*Acknowledgements.*—The move to acquire an area for a 'Pilot Scheme' was initiated by Mr. G. S. Cowley, then Agricultural Officer at Machakos, and his enthusiasm was largely responsible for the starting of these experiments. Much of the field work was carried out by Mr. J. S. Bagenal, Assistant Agricultural Officer, to whom the authors are indebted for many useful observations. We wish to acknowledge the help and encouragement of the Provincial Agricultural Officer, Mr. J. T. Moon, and of other officers of the Department of Agriculture. Finally our thanks for the details of African agriculture under European management are due to Major F. H. de V. Joyce, who kindly read the manuscript and made several helpful criticisms.

## REFERENCES

1. Report by the ULU Settlers' Association to the E.A. Commission. H.M.S.O., Comd. 2387.
2. V. A. BECKLEY, Kenya Dept. Agric., 1930, Bull. No. 4.
3. Kenya Land Commission Evidence. Vol. II. 1933, pp. 1313, 1356, 1362.
4. A. C. MAHER, Report to the Kenya Dept. Agric., 1937. Soil Erosion and Land Utilization in Ukamba (Machakos) Reserve.
5. —— Development of Soil Conservation in Kenya Colony. *World Crops*, 1951, 3, 215.

*Also*: Kenya Dept. Agric. Ann. Report, for 1932, p. 8.

(*Received July 7, 1952*)

*a.* Typical condition before clearing and cultivation (Photo. by African Information Services).

*b.* Grazing the established plots. Panicum (Makarikari) grass in foreground, Rhodes grass beyond.

# CONCEPTION-RATE AND PERIODICITY IN THE BUFFALO

E. S. E. HAFEZ

(*Faculty of Agriculture, Fouad I University, Cairo, Egypt*)

LARGE losses due to sterility or low fertility occur every year among the buffalo in many countries, and although this fact is recognized by most workers in the field, there has been no controlled investigation to throw light on them. Conception in the buffalo may occur all the year round even in the wild state [1, 2], but there is a seasonal trend in the fertility-level as reported in India [3], in the Philippines [4, 5, 6], and in Bulgaria [7]. In the Philippines, conception in the buffalo takes place throughout the year, and high sexual activity is observed during the rainy season and cooler months [8]. The average calving interval for the Egyptian buffalo is 502 days as reported by Asker and Ragab [9], and 595 days as stated by Khishin [10]. In cattle, seasonal differences in fertility-level have been found [11, 12, 13] and are reported to be correlated with the monthly average day-length, there being a lag of approximately 1 to 2 months before the maximum effect is reached [14].

The mean cycle-length is stated to be 21 days for the Indian [15] and the Bulgarian buffalo [7]. Ocampo [6], however, claims that the cycle-length of the Indian buffalo is 37 days, and for the Philippine carabao 34 days.

This paper deals with a study of the conception-rate and breeding efficiency of the buffalo-cow under natural breeding conditions. The effects of year, age, live-weight, consequence of conception, and previous breeding have been investigated.

## *Material and Methods*

Eighty-seven Egyptian buffalo-cows (foundation animals) and their descendants were kept at the Animal Breeding Research Farm, Cairo. They were fastened in double-row stables by means of chains and neck-halters. Buffalo-cows were mated at the first signs of oestrus after a minimum service period of 60 days. During one heat-period the animals were served two or three times at periods of 4 to 8 hours. Dates of matings and calvings were recorded. To ascertain the date of conception, it was recalculated by counting back 317 days from the date of calving. The mating season was arranged according to farm conditions so that the calvings occurred during the winter months (season of green fodder). The animals were weighed monthly and tested for tuberculosis at annual intervals. They were fed individually according to milking capacity. Culling was carried out yearly at a very early age (a few months after birth). Buffalo-bulls, which were kept apart from the females, were tested for fertility before the mating season; 381 calvings resulted from 444 matings during twelve mating seasons (1938–49). Conception-rates were based on calving and on abortion results.

[Empire Journ. of Exper. Agric., Vol. 21, No. 81, 1952.]

## *Results*

### *Conception-rate*

In this study, the buffalo-cows were grouped into two main groups, those conceiving and not conceiving, each of which was classified according to number of services recorded. The breeding efficiency of any particular group was calculated as the number of animals conceived expressed as a percentage of the total number served. The 'repeat-breeder buffalo-cow' denotes that it conceived after more than one service. In different mating seasons the number of conceptions requiring only one service ranged from 38·10 to 80·00 per cent. with an average of 55·63 per cent. The number of conceptions that required two services ranged from 9·26 to 39·58 per cent. with an average of 21·62 per cent., whilst those which resulted from three or more services ranged from nil to 13·04 per cent. with an average of 7·66 per cent. In some cases conception did not occur, although the buffalo-cows were served at one to seven heat-periods. In different years the number of conceptions which failed to occur after one service ranged from nil to 16·36 per cent. with an average of 7·21 per cent. Animals that were served twice without conception ranged from nil to 12·50 per cent. with an average of 4·51 per cent. Buffalo-cows which were served at three or more heat-periods and did not conceive ranged from nil to 19·05 per cent. with an average of 3·60 per cent. As a whole, the number of services required per conception ranged from 1·14 to 1·67 with an average of $1·46 \pm 0·07$. Year-differences in this respect were significant (1 per cent. level). The breeding efficiency of the year-groups ranged from 72·73 to 100 per cent. with an average of 85·80 per cent. In general the data showed that the fertility-level fluctuated throughout the successive years.

The proportion of conceptions requiring only one service was lower in maiden heifers (2 years old) than in other buffalo-cows (aged 3 years and more). Conceptions requiring two services were higher in maiden heifers than in older ones (Table 1). Maiden buffalo-heifers required more services per conception than older ones (significant at 5 per cent. level). The breeding efficiency was 8·62 per cent. higher in maiden heifers than in other buffalo-cows.

TABLE 1. *Effect of Age on Conception-rate in Buffalo-cows*

| *Age-groups* | *Maiden heifers (aged 2 years)* | *Bred before (aged 3 and over)* |
|---|---|---|
| Total no. of matings | 96 | 348 |
| Per cent. of conceptions requiring one service | 47·92 | 57·76 |
| ,, ,, ,, ,, two services | 35·52 | 17·82 |
| ,, ,, ,, ,, three or more services | 8·33 | 7·47 |
| Per cent. of non-conceptions after one service | 4·17 | 8·05 |
| ,, ,, ,, ,, two services | 1·04 | 5·46 |
| ,, ,, ,, ,, three or more services | 3·13 | 3·74 |
| Average no. of services per conception | $1·57 \pm 0·10$ | $1·39 \pm 0·31$ |
| Breeding efficiency (animals pregnant per 100 mated) | 91·67 | 83·05 |

The animals were also divided into two classes denoting those which were bred from and those not bred from the previous year, all ages being included. The percentage of buffalo-cows which conceived after one service was 63·53 per cent. in animals bred from the previous year, and 56·44 per cent. in those which did not calve the previous year. There were no significant differences in the number of services per conception and in the breeding efficiency.

It is important to study the breeding efficiency of the individuals in successive years, and to follow the reproductive performance of repeat-breeder buffalo-cows. There were great individual differences in the conception-rate during the successive years. The individuals fell into three main groups. Group I conceived practically yearly (every 13–14 months) and they always required only one service. Group II were the persistent repeat-breeders; they often calved every other year. Group III, however, were not consistent throughout their reproductive life: they conceived after one service for a few successive years and in certain years they either conceived after more than one service or failed completely to conceive. All the high milk-yielders belonged to Group III. In general, service-rate at first conception gave no indication of breeding efficiency at next conception or during the whole life-time. From a comparison of the breeding performance of 11 foundation buffalo-cows and their descendants, correlation between dams and daughters in respect of number of services required was not significant. Animals which aborted required more services per conception than normally calving ones. The live-weight at the beginning of the mating season, which varied from 370 to 640 kg., had no significant correlation with the conception-rate. There was no evidence that any particular sire got an excess of female or male calves. Nor was there a tendency for the individual cows to produce only males or females during their life except in one case when seven consecutive males were produced.

*Cycle-length*

In this study, 235 oestrous cycles were included, all of which occurred after service by a fertile buffalo-bull and subsequent failure to conceive. The oestrous cycles fell into five groups, according to their length: short, single, double, triple, and very long cycles (Tables 2). Normal single cycles, which occurred in 40·43 per cent. of the cases, ranged from 11 to 30 days with an average of $21{\cdot}14 \pm 0{\cdot}72$ days. Double cycles (with one silent heat in between) occurred in 30 per cent. of the cases and had an average of $43{\cdot}94 \pm 0{\cdot}94$ days, whilst triple cycles, which occurred in 11 per cent. of the total, had an average of $69{\cdot}28 \pm 1{\cdot}02$ days. The average cycle-length deduced from the combined data was $22{\cdot}00 \pm 0{\cdot}66$ days, which included all single cycles, double cycles (split into two) and triple cycles (split into three).

Silent heat occurred in 38·71 per cent. of the total expected oestrous cycles (including double and triple cycles only). The oestrous cycles tended to be prolonged if they followed silent heats. In other words, the mean length of double cycles split into two was longer than the mean length of single cycles (significant at 1 per cent. level). Also, the mean

length of triple cycles split into three was longer than the mean length of double cycles split into two and of the mean length of single cycles (significant at 0·01 and 0·1 per cent. respectively).

The frequency distribution of the cycle-length did not show a normal distribution (Fig. 1), cycles of 15, 23, 26, and 28 days being quite frequent. However, the mode for the length of single, double, and triple cycles was 21, 44, and 63 days respectively. Very long cycles (90–138 days) were as frequent as very short ones (2–10 days). The breeding efficiency following cycles of approximately 3 weeks (19–23 days) was higher than those following cycles of 2–18 days and of 28–30 days.

TABLE 2. *Cycle-length following Failure to Conceive in the Buffalo-cow*

(All data included)

| *Type of cycle* | *Range (days)* | *No. of cycles observed* | *Percentage of total* | *Mode (days)* | *Mean (days)* ± S.E. |
|---|---|---|---|---|---|
| Short | 1–10 | 20 | 8·51 | 7 | 6·40 ± 0·35 |
| Single | 11–30 | 95 | 40·43 | 21 | 21·14 ± 0·72 |
| Double | 31–60 | 70 | 29·79 | 44 | 43·96 ± 0·94 |
| Triple | 61–90 | 25 | 10·64 | 64 | 69·28 ± 1·02 |
| Very long | 91–138 | 25 | 10·64 | . . | 95·40 ± 4·28 |

## *Discussion*

There are several ways of expressing herd fertility. The proportion of animals in the herd conceiving at first, second, and third or more services is the best measure of fertility. Yearly differences in the conception-rate and breeding efficiency reflect the influence of the environment. The close relationship between various environmental factors and normal functioning of the genitalia has been indicated by foremost authorities on the physiology of reproduction. Failure to conceive is not necessarily characteristic of the individual, although some buffalo-cows are always repeat-breeders and others require only one service. Meanwhile it appears that the character of repeat-breeding in the buffalo-cow is not inheritable (as shown by dam–daughter comparisons). It may be concluded that the environment plays an important role in conception; factors such as nutrition, disease, management, and climatic conditions may be involved. The operating factors do not seem to be confined to one particular age or to one particular year. A possible genetic background of failure of conception may be involved.

The breeding efficiency of maiden animals is not very superior to that of older ones. This is explained by the early culling of shy breeders, abortion-reactors, and bad producers. Virgin heifers require more services per conception than heifers of other age-groups, and this agrees with what occurs in cattle [16, 17]. It is believed that delayed breeding in cattle with subsequent non-interruption of the sexual cycles over a period of years leads to a state of 'fatigue' or exhaustion of the anterior pituitary function, with failure of this organ to produce and secrete

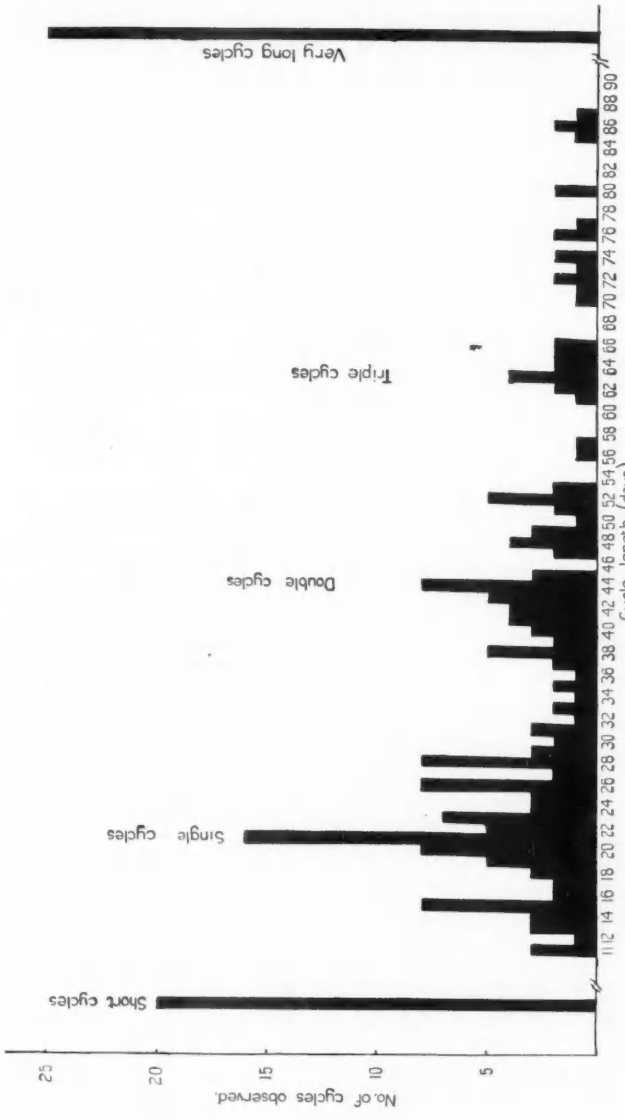

No. of cycles observed.
25
20
15
10
5
Short cycles
Single cycles
Double cycles
Triple cycles
Very long cycles
Cycle length (days)
12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52 54 56 58 60 62 64 66 68 70 72 74 76 78 80 82 84 86 88 90

FIG. 1. Frequency distribution of the cycle-length in the buffalo-cow (all age-groups).

luteinizing hormone (L.H.) as shown by histological evidence [18]. The present data show that delayed breeding for one year does not result in any apparent functional sterility (as measured by the breeding efficiency) in the buffalo-cow.

The occurrence of silent heat in the buffalo is considered high relatively to other species of farm animals. It must be mentioned here that long cycle-length as reported by other authors (e.g. the cycle-length is 37 days [6]) is not actually one cycle but two cycles intervened by one silent heat. In the present data, the high frequency of very long cycles may be due to embryonic mortality in the first few weeks following conception. Conception followed by embryonic mortality may explain the case of those individuals which were served once but neither calved nor showed any oestrous activity during the mating season. Buffalo-cows conceiving at the first *post-partum* oestrus (some 21 days) may be also subjected to early embryonic mortality and the cessation of oestrous activity for 92 days *post partum* [19]. The occurrence of short cycles (1–10 days) has also been observed in virgin non-pregnant and *post-partum* buffalo-cows [19]. Such cycles may be similar to the split oestrus observed in mares by Andrews and McKenzie [20]. If this is so, these periods should not be considered as real cycles, as they will not be accompanied by ovulation in the first place.

Individuals showing an excellent exterior and appearing to be constitutionally robust and vigorous, and therefore used extensively in breeding, may have very poor fertility. It is possible that the high milk-yielders are of low reproductive efficiency or are hard breeders due to the heavy drain on phosphates by high milk-yield. It is also possible that the high concentration of lactogenic hormones in these animals disturbs the hormone balance of the animal. It is of great interest to note that the highest percentage of individuals which conceived after one service occurred during the mating season 1943–4, when foot-and-mouth disease was present in the herd. No explanation of this observation is forthcoming.

An effort is needed to evaluate the importance of early foetal or embryonic death followed by unseen abortion or resorption. It is suggested that physiological, pathological, genetic, and nutritional studies should be undertaken on the reproductive tract of the buffalo-cow so as to find a more adequate assessment of fertility than by the number of services required per conception or the percentage of pregnancy.

*Summary.*—Conception and oestrous cycles performed during twelve mating seasons were studied in the buffalo-cow. The percentages of conceptions which required one, two, and three or more services were 55·63, 21·62, and 7·66 respectively. The average number of services per conception was $1{\cdot}46 \pm 0{\cdot}31$, and the average breeding efficiency for the whole season was 85·80 per cent. More services per conception were required for maiden heifers and for aborted buffalo-cows than for old or calving ones respectively. Conception-rate for one mating could not be predicted from the preceding one; nor could lifetime average of daughters be inferred from that of their dams. Conception followed by

embryonic mortality in some cases is suggested. Both environmental and genetic factors may play a part in conception.

Normal single cycles which occurred in 41 per cent. of the cases had an average of $21{\cdot}14 \pm 0{\cdot}72$ days. Double cycles ($43{\cdot}94 \pm 0{\cdot}94$) occurred in 30 per cent. of the cases, whilst triple cycles ($69{\cdot}28 \pm 1{\cdot}02$) occurred in 11 per cent. Silent heats seemed to prolong the subsequent cycle-length.

*Acknowledgement.*—This work was carried out at the Animal Breeding Research Farm, Giza, Egypt. Thanks are due to Prof. A. Badr-Eldin for providing facilities and for criticism.

## REFERENCES

1. G. C. Shortridge, The Mammals of South West Africa, Vol. 2, 1934. Heinemann, London, p. 439.
2. Zoo; Records of Zoological Gardens, Cairo, 1952.
3. C. N. Dave, A Study of Surti Buffaloes reared at the Poona Agric. Coll. Dairy. Agric. Live-Stk. India, 1938, **5,** 47.
4. V. Villegas, The Trend of Sexual and Reproductive Season among Horses, Cattle, Water-buffaloes, Sheep and Goats under Los Banos Conditions. Philippine Agric., 1928, **17,** 477.
5. M. Manresa and D. Diapo, Studies on the Breeding Habits of Cattle. Ibid., 1938, **26,** 870.
6. A. R. Ocampo, Further Studies on the Breeding Habits of the Carabao. Ibid., 1939, **28,** 286.
7. B. Kaleff, The Buffalo for Live-stock Breeding (in German). Z. Zücht., 1932, **24** B, 391.
8. T. V. Rigor, Observations on the Breeding Season of Native Carabaos at Alabang. Philipp. J. Anim. Indust., 1947, **9,** 15.
9. A. A. Asker and M. T. Ragab, The Generation Interval in Egyptian Live-stock. Faculty of Agric., Fouad I Univ., 1951, Bull., No. 6.
10. S. S. Khishin, Studies on the Egyptian Buffalo: I. Average Age and Calving Interval. Empire J. Expt. Agric., 1951, **19,** 185.
11. J. Anderson, Climate and Reproduction in Cattle. 1st Int. Congr. Physiol. and Pathol. Reprod., Milano, 1948.
12. Z. Csukas, The Role of Carotene in the Periodicity of Reproduction of Mammals. Mag. allatorv, Lapja, 1949 (14) (Anim. Breed. Abst., **18,** 165).
13. I. Maletto, Some Secondary Factors which influence Fertility in Cows. Zootec. e vet., 1951, **6,** 189 (Anim. and Breed. Abst. **19,** 334).
14. E. Mercier and G. W. Salisbury, Seasonal Variations in Hours of Daylight associated with Fertility Level of Cattle under Natural Breeding Conditions. J. Dairy Sci., 1947, **10,** 747.
15. C. O. Levine, The Water Buffalo: A Tropical Source of Butter-fat. J. Hered., 1920, **11,** 51.
16. J. Quinlan and L. L. Roux, The Influence of Dry Rations, Lack of Exercise and Lack of Sunlight on Reproduction in Beef Heifers and Cows. Onderstep. J. Vet. Sci. Anim. Indust., 1936, **6,** 719.
17. R. F. Morgan and H. P. Davies, Influence of Age of Dairy Cattle and Season of the Year on the Sex Ratio of Calves and Services required for Conception. Neb. Agric. Expt. Stat. 1938, Res. Bull. No. 104.
18. M. de Lange, The Influence of Delayed Breeding on the Fertility of Beef Heifers. Onderstep. J. Vet. Sci. Anim. Indust., 1950, **24,** 125.
19. E. S. E. Hafez, Oestrus and Conception *Post-partum* in Domestic Animals. Proc. II Int. Congr. Physiol. and Pathol. Reprod. Artif. Insem., Copenhagen, 1952, p. 101.
20. F. N. Andrews and F. F. McKenzie, Mo. Agric. Expt. Stat., 1941, Res. Bull. No. 329.

(*Received April 22, 1952*)

# THE INFLUENCE OF FARM PRACTICE ON THE PRODUCTIVITY OF FIELD BEANS

M. H. R. SOPER

(*Department of Agriculture, Oxford University*)

In recent years there has been considerable speculation concerning the possible reasons for the reduction in the acreage of Field Beans from the 500,000 acres grown in the 70's to the 120,000 acres grown today. In a survey of farmers' crops, carried out near Oxford in the years 1947–9, the following reasons were given for the unpopularity of the crop:

1. Insufficient winter hardiness to survive a severe winter.
2. Inability to withstand attack by Chocolate Spot (*Botrytis cinerea*).
3. Risk of attack by Bean Aphis or Black Fly (*Aphis fabae*).
4. Absence of reliable strains either from deterioration of stocks or neglect by breeders.
5. Insufficient farmyard manure.
6. Difficulties in keeping the crop clean, owing to labour shortage.

In this survey, developmental studies were made during the season, and the following details collected from growers: (1) the soil type, (2) the previous cropping of the field, (3) the fertilizers or manure applied, (4) the date of sowing, (5) the quantity of seed used, (6) the width of the rows, (7) the method of planting, (8) the source of the seed. Plant-counts were made by taking 100 random yard-lengths across the fields in March, April, and July (a statistical check showed this to be an adequate number), and stem and pod counts were made at harvest. Hence figures for plant, stem, and pod densities per acre could be calculated, and also the average number of stems and pods on each plant. The only data lacking were for the actual yield of beans, but owing to insufficient accuracy at threshing, a reliable figure could not be obtained in most cases, and the figures of pods/acre had to be taken as the criterion of yield, previous work [1] having shown that this does give a good estimate of yield, which is not greatly affected by variation in pod and bean size. The analysis of the data on plant development, which is being published elsewhere [2], shows that both the season and the level of fertility of the field exert a profound influence on the establishment and development of the crop. As plant densities increase, the number of pods per plant decreases under all conditions. The number of pods per *acre* increases with increasing plant density only if the land is above the average in fertility. This does not apply to fields of low fertility, and here also there is a negative correlation between plant density and stems per plant, which does not hold on high fertility land. With low plant-populations, therefore, there may be a compensatory effect in the shape of more branches and/or better pod-production per plant, depending on the growing conditions. The compensatory effect cannot be relied upon to make up entirely for low plant-numbers, and

[Empire Journ. of Exper. Agric., Vol. 21, No. 81, 1953.]

it is safer to try to establish a high plant-population in the first place in order to ensure a good yield of pods per acre.

*The soil type.*—The soils of Oxfordshire and Berkshire are extremely variable; included in the survey were crops growing on clays (Oxford and Gault), heavy loams, Cotswold brash, and even light sands. The distribution of the sixty crops was as follows:

| | *No. of fields* | *% of total* |
|---|---|---|
| Clays . . . | 36 | 60 |
| Heavy loams . . | 4 | 8 |
| Cotswold brash . . | 11 | 17 |
| Light soils . . | 9 | 15 |
| | 60 | 100 |

Beans are regarded primarily as a heavy-land crop, a contention which receives some support from the above figures. Crops growing on the heavier soils seem to survive the winter more satisfactorily, provided that waterlogging does not occur; this can be fatal on any type of soil, for the tap-root rots very quickly, and the plant never fully recovers from that loss. Crops on lighter soils do not generally make such vigorous vegetative growth and are inclined to wilt more readily in periods of high temperature at, and soon after, flowering—a factor which may be of importance in pod-formation.

Of the 29 crops harvested in 1948 and 1949 (the 1947 results have been omitted because the year was so atypical climatically that the figures are not truly representative of bean-growing in a normal year), 16 were grown on clays or heavy loams, and 13 on brash or lighter soils.

TABLE 1. *Comparison of Results on Heavy and Light Soils. 1948 and 1949 Seasons*

| *Mean* | *Plants/acre 000's* | *Stems/plant* | *Pods/plant* | *Pods/acre 000's* |
|---|---|---|---|---|
| Heavy soils (16)* . . | 77·5 | 1·90 | 9·8 | 730 |
| Light soils (13) . . | 65·8 | 1·85 | 10·0 | 581 |
| Sig. diff. . . . | 17·2 | 0·28 | 2·6 | 121 |

* Number of crops.

The difficulty in applying statistical analysis to data derived from a field survey lies in the great diversity of field conditions, both natural and applied, encountered even within a relatively small area. At the same time, the number of crops that it is possible to handle efficiently is limited, so that in general the mean differences between the functions studied, have to be large, and this factor must be borne in mind in considering Table 1 and the succeeding tables. The difference in the average plant-populations in July on the two types of soil, though considerable, fails to reach significance, whilst the figures for stems per

plant and pods per plant are almost identical. The figure for pods/acre, which is the most important from the aspect of yield of crop, is quite significantly in favour of the heavier land. As the figures for pods per plant are similar and plants per acre not significantly different, this must mean that on heavy soils the higher plant populations carry more pods, thereby increasing considerably the gross yield of pods. The significant result obtained in the figures for pods per acre substantiates the traditional belief that the crop is more reliable on heavy land.

*Use of fertilizers and farmyard manure.*—Many years ago Oldershaw [3] at Saxmundham demonstrated the value of F.Y.M. and of phosphate and potash in the production of the crop on heavy land. More recently Boyd [4] analysed various experiments at different centres and again demonstrated the value of a combination of phosphatic and potassic fertilizers. In spite of this, the results of the survey (Table 2) show a rather disturbing picture of fertilizer use.

TABLE 2. *Analysis of Manurial Treatment*

| *Manures used* | *No. of crops* | *% of total* |
|---|---|---|
| No fertilizer or manure | 23 | 38·3 |
| F.Y.M. only | 10 | 16·6 |
| F.Y.M. and 'artificials' | 4 | 6·6 |
| Phosphate only | 12 | 20·0 |
| Phosphate and potash | 3 | 5·0 |
| Compound fertilizer | 7 | 11·6 |
| Potash only | 1 | 1·9 |
| | 60 | 100·0 |

Nearly 40 per cent. of the fields received no fertilizer at all, and only 22 per cent. received the F.Y.M., which is widely thought to be necessary for a good crop. Approximately 40 per cent. of the fields received dressings of inorganic fertilizers, though half of these received phosphate only, whereas Boyd's analysis showed that phosphate together with potash gave the best results. Only 18 per cent. of the fields were dressed with potash fertilizers. These figures assume even greater importance when associated with those in Table 3.

TABLE 3. *Previous Cropping of Fields*

| *Crop grown after:* | *No. of fields* | *% of whole* |
|---|---|---|
| (1) Two consecutive cereals | 23 | 38·3 |
| (2) One cereal crop | 31 | 51·8 |
| (3) Fallow | 4 | 6·6 |
| (4) Other crops | 2 | 3·3 |
| | 60 | 100·0 |

Again nearly 40 per cent. of the crops were following two consecutive cereals, and further analysis shows that half of these fields were in

the group that received no manurial dressing of any kind. It can be appreciated that if fertilizers are of value to the bean crop, many of these fields were not getting an adequate application in view of their previous cropping history.

If the 1948 and 1949 fields are again grouped, it is found that twelve fields received neither fertilizer nor F.Y.M., that twelve fields received 'artificials' in various forms, and that five fields received F.Y.M. alone, or in association with 'artificials'. Again the relatively small numbers in each group, and the diversity of the data mean that differences must be large to reach significance. The summarized results are given in Table 4.

TABLE 4. *Manurial Applications and Plant Development*

| *Treatment* | *Mean of* | *Plants/acre 000's* | *Stems/plant* | *Pods/plant* | *Pods/acre 000's* |
|---|---|---|---|---|---|
| (1) No fertilizers . . | (12)* | 66·2 | 1·74 | 9·6 | 579 |
| (2) 'Artificials' . . . | (12) | 72·3 | 2·02 | 10·5 | 694 |
| (3) F.Y.M. . . . | (5) | 86·4 | 1·86 | 9·3 | 791 |
| Sig. diff. (1) (2) . . . . | | 18·6 | 0·30 | 2·8 | 128 |
| Sig. diff. (1) or (2) (3) . . . | | 24·4 | 0·38 | 3·6 | 168 |

* Number of crops.

With so few fields in the F.Y.M. group, it would be dangerous to be too dogmatic, for it might be that those farmers who applied F.Y.M. were farming at a generally higher level, e.g. sowing the crop earlier, using higher seed-rates, and producing from land with greater crop-producing potential. Even though there are no significant differences between plant-numbers, there is a marked upward trend in plant-establishment from the 'no fertilizer' fields to the 'F.Y.M.' fields. The figure of 86,400 plants per acre is fairly near the optimum plant-density for a high yield on average land, whereas the figure of 66,200 is definitely below it. The fields that received 'artificials' appeared to branch and to pod more satisfactorily than the unfertilized fields, though a reduction in pod-numbers might have been expected in view of the inverse correlation found elsewhere [2] between pods per plant and plants per acre; this no doubt accounts for the smaller figure on the F.Y.M. fields; in yield of pods per acre the F.Y.M. fields significantly outyield those that received no fertilizer, though the other two differences just fail to reach significance. Taking an average of 2·5 beans per pod and a bean-weight of 0·55 gm. (a conservative figure in both cases), the yields for the three groups are 15·8, 18·5, and 21·3 cwt. per acre respectively. These differences are considerable, and are large enough to mean a profit or loss on the crop. It must also be remembered that they are average yields, and that in practice quite a number of fields must have recorded yields of well below 15 cwt. per acre, and the difference of 3 cwt. per acre would fully justify the expenditure on fertilizers even at present-day prices.

*Plant establishment.*—From the preceding results it is clear that one of the major factors in obtaining a satisfactory yield is successful plant-

establishment, and that a high plant-population will ensure a good total yield of pods, even though the individual plants carry a smaller number. The most important factors in establishment are: (1) date of sowing, (2) quantity of seed sown, (3) avoidance of bird-damage, and (4) health and quality of the seed. The method of sowing must also be considered, but it is possibly less important than the other factors.

*Date of sowing.*—Sowing-dates during the 3 years (Table 5) varied between Sept. 28 and Nov. 25.

TABLE 5. *Dates of Sowing*

| *Date* | *No. of crops* | *% of total* |
|---|---|---|
| Before Oct. 16 . . | 14 | 24 |
| Oct. 16–31 . . | 26 | 43 |
| Nov. 1–15 . . | 18 | 30 |
| After Nov. 15 . . | 2 | 3 |
| | 60 | 100 |

Exactly one-third of the crops was sown after the beginning of November, which is at least a fortnight after the optimum time. Some farmers maintain that the crop should be sown early in October even at the risk of winter proudness and the danger of late spring frosts damaging the early flowers. Others prefer a later date for sowing because they fear serious damage from these two causes, and they maintain that a later sowing does not suffer seriously from hard frosts during the winter. The results from 1948 and 1949 definitely confirm the value of early sowing; in these years eight farmers sowed their crops before Oct. 15, thirteen between Oct. 15 and 30, and eight sowed after the beginning of November (Table 6).

TABLE 6. *The Influence of Sowing-date*

| *Date of sowing* | *Plants/acre 000's* | *Stems/plant* | *Pods/plant* | *Pods/acre 000's* |
|---|---|---|---|---|
| (1) Before Oct. 16 (8)* . | 87·0 | 1·97 | 9·3 | 783 |
| (2) Oct. 16–31 (13) . . | 68·2 | 1·85 | 10·0 | 631 |
| (3) After Nov. 1 (8). . | 63·9 | 1·82 | 10·3 | 595 |
| Sig. diff. (1) (3) . . | 22·4 | 0·39 | 3·6 | 166 |
| Sig. diff. (1) or (3) (2) . | 19·9 | 0·35 | 3·1 | 152 |

* Number of crops.

There is a striking gradient in favour of the early sowing-date in every measure except that of pods per plant, where the inverse correlation between plant-density and pod-production has again come into play. If the first fortnight in October is compared with the first fortnight in November, there is a significant improvement in plant-establishment from the earlier sowings, and a higher yield of pods per acre.

The figures for plants should, however, be treated with some reserve for six of the farmers in the first group sowed more than 3 bu. of seed per acre, whereas only three farmers out of the eight did so in the second group, and this might tend to weight the evidence in favour of the first group. The whole evidence over the 3 years of the survey, and particularly in the very hard winter of 1947, points to the beneficial effect of sowing before the middle of October, both from the aspect of plant-establishment, and also of ensuring a high final yield. In 1947, a higher proportion of the late-sown crops were ploughed up as failures, and observations in the field showed that well-grown plants were able to withstand the low temperatures more satisfactorily.

There was no evidence in this survey that the early sowing had jeopardized the crop during the succeeding winter and early spring, though one crop sown in September did make excessive vegetative growth during the succeeding summer, and the level of pod-production was not high.

*Rate of seeding.*—Opinions on the correct seed-rate are conflicting. The more successful growers in general seem to prefer a relatively high rate of seeding, i.e. 3–4 bu. per acre, though a few will maintain that on land in a good state of fertility less than 3 bu. should be sown. Two points have to be considered: (1) The effect of plant-density on pod-production; and (2) the liability of the crops to suffer damage from frost, disease, or pests. If the crop is being grown on land of even slightly above average fertility (as it should be) there is, as has been shown [2], a correlation between plant-numbers and pods per acre, and therefore every advantage to be gained from using a relatively high rate of seeding, for this will provide a safety margin of plants to offset possible wastage. With a low seed-rate, there is always the risk of a particularly hard winter, or of fungal or virus disease, or rook and pigeon infestation, causing a severe wastage of plants during the period of establishment, so that a small seeding is always dangerous.

The figures in Table 7 show the results that might have been expected.

TABLE 7. *Influence of Rate of Sowing*

| *Seed-rate* | *Plants/acre* 000's | *Stems/plant* | *Pods/plant* | *Pods/acre* 000's |
|---|---|---|---|---|
| bu./acre 2–3 (14) . . | 60·9 | 2·0 | 10·9 | 630 |
| ,, 3½–4 (15) . . | 82·7 | 1·76 | 9·0 | 694 |
| Sig. diff. . . . | 15·6 | 0·27 | 2·5 | 131 |

The higher rate of seeding has led to significantly better plant-establishment and markedly higher densities throughout the season, but this better plant establishment has been counteracted to some extent by a higher rate of branching and apparently better pod-production on the thinner fields, so that there is no significant difference in the total production of pods per acre. This result applies to fields of high and low fertility which were fairly distributed in each group, but in view of the

various hazards in establishment, a high rate of seeding is clearly desirable.

*Method of sowing.*—The older practice of ploughing in the seed appears to have become less common, for out of sixty crops, only eight were ploughed in, and the remainder were drilled. There are insufficient numbers available in the 'ploughed-in' group (some of these perished in the 1947 winter) for an adequate comparison to be made.

From the point of view of the subsequent cleaning of the crop by mechanical means, drilling is to be preferred. There was evidence, however, that with the drill the seed was often sown too shallow, especially on the lighter or silty types of soil, where the land tends to pack down after heavy rain. When this occurs, the tender stem of the young plant is left exposed, and there is a very great risk of tissue damage from low temperatures, and of the subsequent death of the plant. It is probable that in terms of yield there is little to choose between ploughing-in and drilling, provided that they are properly carried out, but where bird-damage is expected, ploughing-in is the best course, and where subsequent hoeing is important, drilling is preferable.

*Width of the row.*—Of the 52 crops that were drilled, 47 were sown at row-widths varying from 18 to 24 in., 3 crops were sown at 14 in., and 2 crops at 7 in. There is no means of ascertaining from these figures, which is the most satisfactory distance. If beans are still to be regarded as a cleaning crop, there is no doubt that a row-width of 20–24 in. is to be preferred, for mechanical hoeing is possible, and it is easy to pass between the rows for a subsequent hand-hoeing if this can be carried out. Konold [1] has found little difference in yield from varying row-widths, provided that seed-rate is constant: a finding which has been supported by preliminary experiments at Oxford, and if subsequent work confirms these initial results, the best row-width to use will be that which enables the maximum cleaning to be carried out at the minimum cost, viz. 20–22 in.

*Source and quality of the seed.*—Table 8 shows that approximately 50 per cent. of the farmers bought seed from their merchants, whilst 40 per cent. used their own seed. The rest purchased direct from other farms.

TABLE 8. *Origin of Seed*

| *Source* | *Number* | % |
|---|---|---|
| Merchant . . . | 31 | 52 |
| Own seed . . . | 24 | 40 |
| Other farmers . . | 5 | 8 |
| | 60 | 100 |

There were a few complaints of poor quality, and an inspection of some samples revealed a high degree of infestation with the bean beetle. More important than external appearance, however, is the health and vitality of the seed. The early field inspections frequently showed relatively poor germination, even though the cultivations had been carried

out satisfactorily. There is little doubt that fungus diseases can take a serious toll of young plants at, or soon after, germination. Whether the infection is carried with the seed, or gains access to the young shoot as it emerges, could not be determined with certainty. On some fields, the former appeared most probable, for many plants could be found that were severely affected with stem fungal infections, which seemed to have moved upwards from the seed. These gave rise to a stem-blackening that resembled a form of *Botrytis cinerea*, which ultimately proved fatal to the plant. In other cases, the seed did not germinate and could be found rotting below the surface. Observations also showed blackening and crinkling of the young leaves, suggestive of virus infection, though absence of adequate laboratory facilities made it impossible to confirm this tentative conclusion. It is quite clear that there is a heavy wastage of young plants during the first 3 months of life, and the evidence points to pathogenic causes, originating in many cases from the seed.

When the theoretical plant-population is compared with the established crop, it is found that there is a very large discrepancy in plant-numbers. A seed-rate of 3 bu. per acre should give a population of approximately 170,000 plants per acre (Table 9).

TABLE 9. *Plant Densities 1947–49 in 000's Plants per Acre*

| | *March* | *April* | *July* |
|---|---|---|---|
| 1947. . . | 74·4 | 60·2 | 42·6 |
| 1948. . . | 76·0 | 72·5 | 63·9 |
| 1949. . . | 92·0 | .. | 85·9 |

Thus at least 50 per cent. of the theoretical plant is lost between sowing and the middle of March. A proportion of this loss is due to the failure to germinate, and to the fungal infections previously discussed, but observations show that rooks and pigeons can often be responsible for wastages of 20,000–30,000 plants per acre.

*Bird-damage.*—The critical period usually occurs shortly after shoot-emergence, for the rook can then see the plant and will dig down for the seed. If the crop has not been sown deeply, the birds will move along the rows uprooting each plant in turn. One hundred rooks destroying only thirty plants each can dispose of 3,000 plants in one day, and many growers do not seem to appreciate the damage that is being done to the crop. The four counter-measures that can be adopted are:

1. To soak the seed in a repellent, such as paraffin (which is not a convenient method in practice).
2. To sow as deeply as possible, i.e. 3–4 in.
3. To sow as early as possible.
4. To put black cotton at knee-height across the field in squares of approximately 20 yds. width.

With early sowing the plant is established before the birds have

exhausted the supplies of grain on the stubble fields, and they do not migrate to the bean fields.

*Disease.*—With the exception of low yields, the most frequent reason given by farmers for not growing the crop is the risk of Chocolate Spot (*Botrytis cinerea*). The evidence from the survey and from observations in subsequent years, suggests that this reason is not valid in Oxfordshire. Over the 3 years of the survey only two crops suffered severely from the disease in its common form, and in both cases they were also found to be suffering from potash or phosphate deficiency. In each year, symptoms of the disease could be found on most crops as early as January or February, but these symptoms never progressed beyond the stage of small spots on the leaves, and no visible damage was caused to the crop. Even in 1948, when climatic conditions favoured a rapid spread of the disease, there were only the two above-mentioned fields where it assumed epidemic proportions. On the worst of these fields there was a serious deficiency of available potassium in the soil (this was proved by soil analysis and by observation plots), and the crop was practically worthless except for a few acres which had received F.Y.M. On this area, the crop was fully developed, and though there was widespread spotting on the leaves, the fungus did not gain control and there was a moderate yield. On the untreated area, the combination of potash deficiency and Chocolate Spot reduced the yield to a negligible figure. The evidence, though it is not fully conclusive, points to the value of a high level of fertility in combating the disease. Though the fungus may be a serious cause of loss in some areas of the country, it would not appear to be so in the south Midlands.

*Bean Aphis.*—Another disadvantage frequently mentioned by farmers is the risk of attack by the Bean Aphis or Black Fly (*Aphis fabae*). In this case also, no really serious infestations occurred on winter beans during the three years. Isolated colonies could be found in many of the fields, but there was never any suggestion of a serious reduction in yield. There is little doubt that this pest is more serious with the later developing spring bean than with the autumn-sown crop, and it would not seem to be a serious risk in the area under survey.

*Harvest wastage.*—In certain seasons, the crop is difficult to harvest efficiently owing to the very low setting of the pods on the stem. When this occurs, the knife may cut above the lowest pod-bearing node leaving pods or partially cut pods behind. With a stunted crop, there is also a considerable wastage of the small stems, which either fall away from the platform or are not properly bound in the sheaf; the 1947 season was such a year. Estimates obtained by counts of pods and beans on the field at harvest varied between 74 and 240 lb. per acre. In the 1948 and 1949 harvests there was very little loss, owing to the pods being carried high on the stems.

## *Discussion*

Field beans used to be regarded as a recuperative and a cleaning crop, and as such they tend to follow one or more cereal crops in the rotation. If they are to serve this purpose, there are three requirements to be

met: (1) they should be well manured; (2) there should be a full plant to give a good yield of grain and to smother weeds; and (3) they should be well hoed until the crop is large enough to exert a smothering effect.

The evidence from the survey suggests that some or all of these three requirements are not being met today, and that much of the dissatisfaction with the crop arises from that fact. First, the figures for fertilizer application show that the general level of F.Y.M. and fertilizer application is too low, and that the crop is not getting adequate help in view of its place in the rotation. Secondly, the most important requirement of plants-per-acre at harvest is not being met. This is one of the most important factors in yield on average land of good quality. To ensure a good yield a population of 80,000–90,000 plants per acre in July is desirable. It is true that in *good* seasons, a high yield can be obtained with fewer plants, but a good season is never certain, and it is safer to try to ensure a high density in the first place. The important factors here are date of sowing and seed-rate, and it is recommended that the rate of sowing should never be less than 3 bu. and that the crop should never be sown after October 15. Under good conditions the seed-rate may be increased to 4 bu. Many crops are undoubtedly sown much too late in the autumn, and suffer either from severe climatic conditions or from serious rook-damage.

Another factor in low yields is the loss of plants by disease in the establishment period and from lowered vitality during later development. There is undoubtedly a good deal of unhealthy seed being sown and yields are suffering in consequence. Similarly, many strains are insufficiently hardy to survive really severe winters. The experience of the three years' survey (and of two subsequent seasons) suggests that Chocolate Spot disease and Aphis infection in the area in question were not sufficiently serious to warrant the abandonment of the crop. The former appears to be closely associated with inferior soil conditions, particularly deficiencies of potassium. The serious attacks of Black Fly were associated with spring-sown beans and not winter beans.

## *Summary*

The conclusions regarding the most common causes of dissatisfaction with the crop are:

1. It is frequently grown on land that is not in a sufficiently high state of fertility, or in good physical condition.
2. Insufficient phosphatic and potassic fertilizers are being used.
3. It is generally sown too late.
4. It is advantageous to use a relatively high rate of seeding, viz. 3–4 bu. per acre, particularly on good land.
5. Plant-establishment is often unsatisfactory owing to (*a*) severe winter killing by low temperatures, (*b*) unsatisfactory seed, and (*c*) bird damage.
6. The seed may be diseased, and should be selected only from a healthy crop.

7. Rooks may decimate the crop, or cause wastage at the rate of 20,000–30,000 plants per acre. Every effort should be made to reduce this wastage.

8. Harvest losses may be considerable in certain years, and early sowing should help to avoid excessive loss.

To obtain a good crop, the rules are to sow 3–4 bu. of clean healthy seed during the first fortnight in October on fertile land, and to ensure that phosphatic and potassic status is high.

## REFERENCES

1. O. KONOLD, Der Ertragsaufbau der Hülsen Früchte. Forschungsdienst, 1940, **10**, 41.
2. M. H. R. SOPER, A Study of the Principle Factors affecting the Establishment and Development of the Field Bean (*Vicia faba*). J. Agric. Sci. 1952, **42**, 335.
3. A. W. OLDERSHAW, Experiments on the Manuring of Beans. J. Roy. Soc. Eng., 1922, **83**, 180.
4. D. A. BOYD, Manuring of Beans and Peas. Empire J. Expt. Agric., 1946, **14**, 195.

(*Received March 30, 1952*)

# *PANICUM MAXIMUM*

M. S. MOTTA*

(*Grassland Research Station, Stratford-on-Avon, England*)

*Panicum maximum* is a tufted perennial grass with a somewhat stout stem. Its leaves are bright green; it grows to a height varying from 3 ft. to 10 ft. with leaves up to 2 ft. long, 4–20 mm. wide with and without hairs. Its inflorescence is a panicle that is either erect or nodding and rather loose. The common name is Guinea grass.

*Distribution.*—It is indigenous to Africa, where it is found growing naturally in west, central, and east Africa, and South Africa. The range of distribution is from sea-level to an altitude of around 6,500 ft., mostly in scattered-tree grassland [1], open tall-grass glades, coastal regions, and bush vegetation. Finding its way into most tropical countries it has played a major role in grassland improvement and livestock production in some of these countries.

Outside the areas of Africa previously named, Guinea grass is now grown in French North Africa (Morocco), sub-tropical U.S.A., central America and the Carribean region, South America, India, Ceylon, Malay peninsula, Australia (Queensland), and the East Indies. In all these countries it will grow on a wide range of soil types. Although it is indigenous to Gold Coast and Nigeria, the literature from Sierra Leone [2] suggests that it is apparently not indigenous to that country. *Panicum maximum* now found growing in cultivated pastures, ditches, and along railway lines, is alleged to have originated from seed introduced from the West Indies about 1905–9. It was introduced into the West Indies from other West African countries, some time in the eighteenth century.

It thrives well only in areas that are free from frosts.

*Strains and ecotypes.*—This wide range of distribution, brought about by introductions from different sections of Africa and subsequently from other areas where it has been established, has resulted in the isolation of several different strains and ecotypes. These show marked differences in time of flowering, degree of leafiness, and morphological and physiological characteristics. Some of the recognized strains and ecotypes reported from Puerto Rico, Jamaica, Trinidad, Brazil, Australia, French North Africa (Morocco), Hawaii, are as follows:

Warmke [3] has reported the presence of five types of *Panicum maximum* in Puerto Rico, namely: Local Guinea, Gramalote, Borinquen, Broadleaf, and Fine leaf.

The regular or common Guinea is resistant to drought and heavy grazing and is widely grown in the drier areas of the island. Gramalote is distinguished from regular Guinea by a more robust growth-habit and by universal infection of mature plants by leaf-spot (*Cercospora fusimaculosus*). It is the important pasture and cutting-grass in the more humid areas of the north coast. The form known as Borinquen apparently had its origin in Puerto Rico. The types Broadleaf and Fine leaf are recent introductions from Tifton, Georgia. These are also of African origin.

* Pasture Research Officer, Dept. of Agriculture, Jamaica, seconded to Grassland Research Station, 1950–2.

[Empire Journ. of Exper. Agric., Vol. 21, No. 81, 1953.]

3988.81 D

Recording periods taken from seeding to flowering from plants of these five types grown in pots, there appeared to be a definite relationship between size of plant and age of flowering. The shortest type was Fine leaf, flowering at approximately 71 days of age, next Borinquen at 82 days, then Broadleaf at 100 days, Local Guinea at 135 days, and the most robust, Gramalote, at 148 days. The Gramalote strain is reported to be widely grown in central and South America.

Jamaican strains show distinct morphological differences. The two local strains are known as Silk Guinea and St. Mary's cow grass. Silk Guinea is extremely leafy and is grown extensively in the drier coastal areas of the island and to a less extent at higher elevations. St. Mary's cow grass is much coarser, more hardy, less palatable, and is grown mostly in more humid sections.

There are two well-marked types in Trinidad known as Local Guinea and Colonio [4] (introduced from Venezuela). Local Guinea is the more leafy. Colonio has shown promise only in certain parts of the island, usually being stemmy and flowering freely.

The Brazilian types [5], known locally as Guinea grass, Gongylodes, and Murumbú, also exhibit marked differences. Guinea grass flowers early from December to January, Gongylodes from January to February, and Murumbú in the middle of April. All three are said to be native to Africa and were originally cultivated. They are now distributed over wide areas of the country.

White [6] separated the types of *Panicum maximum* found growing in Queensland (Australia) into three botanical types: Common Guinea (*P. maximum var. typica*); Slender Guinea (*P. maximum var. trichoglume*); Purple-topped Guinea (*P. maximum var. coloratum*). Winders [7] has stated that both the Common and Purple-topped types are robust, whereas Slender Guinea is fine-stemmed. It would appear that *Panicum coloratum* is regarded as a separate species in both Southern Rhodesia and South Africa [8]. Strains have been developed within the species differing greatly in growing habits, e.g. *P. coloratum*—Makarikari strain No. 1412—sends out runners that root readily, whereas *P. coloratum*—Makarikari strain No. 1112—is an erect type that does not send out runners. However, in 1922, Mundy, Blackshaw, and Flack [9] of Southern Rhodesia stated that there were four widely differing grasses identified under the name of *P. maximum* namely, Guinea grass, Fine Guinea grass, Buffel grass, and Purple-topped Buffel grass.

Four Hawaiian strains were introduced into Queensland, for experimental purposes. They were No. 1200, No. 1202, No. 3783, and No. 3820.

French North African workers [10] have observed two different vegetative types growing in Morocco, stating that one type has stems taller than 2·5 metres, with a few very thick spreading panicles; the other is shorter and has less dense but widely spreading panicles.

It is evident that there is a wide range of types of *Panicum maximum* throughout the tropics.

*Seeding habits.—Panicum maximum* flowers profusely but ripening of seeds is very uneven. Reports from nearly every country suggest that

the viability of seed is extremely low. Unevenness in ripening renders collection of seed with fairly high viability very costly and is a factor which has greatly limited the use of this grass in several countries.

Warmke [3] working on the potentialities of strains as seed-producers, observed that for the five types used the viability of seeds ranged from 4·5 per cent. for Borinquen to 48·7 per cent. for Gramalote. The largest portion of viable seeds from all types was formed from 14–21 days after anthesis. Florets formed before this period showed extremely low viability. There was also a reduction in percentage viability of seeds formed at later periods.

These findings indicate that the pattern of seed-setting from anthesis onwards differs very little with strains, but there is considerable variability in the capacity of strains to produce viable seeds.

*Establishment.*—Establishment of *Panicum maximum* can be either vegetative (from rooted sets) or from seed.

When propagated vegetatively, the rooted sets are planted from 18 in. to 2 ft. apart. In some areas stands are allowed to seed and self-sow the inter-spaces. This method of establishment is mostly prevalent in areas of peasant farmers, and where cheap labour is available. Methods of establishment from seeds can be listed as:

1. Direct seeding on a prepared seed-bed, generally broadcast.
2. Seeding under maize, sorghum, or other arable cash crops, either broadcast or in furrows. Distance between furrows varies in different countries and with the type of crop grown.
3. Seeding with a legume or a companion grass.
4. Allowing old pastures to run to seed, followed by forking, ploughing, or burning of stubble after the edible portions have been grazed off.

The methods of establishment vary with rainfall conditions, types of farms and general agricultural, scientific, and economic advancement of the farming communities.

*Seed-rates.*—Successful stands have been obtained in some parts of the world using seed-rates of 6–30 lb. per acre either by direct seeding or undersowing. Other areas have reported rates of 50–100 lb. of seed per acre or the equivalent in panicles containing seed and spread over the field, for direct sowing or with a cover crop. Graham [11] recommends 4 lb. fertile seed in admixture with *Melinis minutiflora* at 3 lb. per acre, to obtain a quick cover under Australian (Queensland) conditions.

*Management and utilization.*—*Panicum maximum* grows luxuriantly in the wet season on a range of soil types of adequate fertility. It withstands drought better than most other high-yielding grasses of the tropics, during the dry months of the year. It is suited to both wet and dry areas. Different strains and the range of ecotypes within the species play a valuable part in achieving this range of adaptability under a variety of environmental conditions.

It can be used for grazing and/or soilage and can be conserved as silage or hay. Under pasture conditions, with good systems of management,

it can withstand intensive stocking and recovers quickly after grazing. If allowed to get out of control it grows tall and stemmy. However, with proper management and rotational grazing it will produce dense leafy growth. Sanders [12], reporting on a tour of Queensland, comments that Guinea grass was maintained in productive condition by keeping it down to a height of only 6 to 8 in. by careful rotational grazing.

In some areas grazing is preferred at a taller stage—around 18 in. to 2 ft.—in order to obtain the best balance between dry-matter yield, nutrient status, and persistency. The cycle of grazing is dependent on environmental conditions, together with seasonal variation. Excessive growth should be avoided. Lack of proper management will invariably lead to excessive and stemmy growth. Even with the best methods of grazing, the rate of growth will be out of proportion to the rate of stocking in the flush periods of growth. In the best systems of management excess grass is cut for conservation in the form of silage. If suitable methods can be devised, haymaking might be a practical and economic possibility in many countries. At present this is done only on a limited scale.

Failing facilities for conserving excess fodder, a mowing-machine should be used to remove excessive stem-growth after the leafage has been grazed off. Maximum growth of good quality should be aimed at for conserving *in situ* for grazing animals to consume in drought periods.

In countries where less intensive systems of management are practised, the hard bony stubble is burnt annually before the onset of the rainy season. Burning must be done with discretion, aiming to avoid damage to the crowns and young shoots. Indiscriminate burning leads to a reduction in number of *Panicum maximum* plants together with the destruction of other valuable bottom grasses in the sward. Soil erosion and pasture deterioration follow. These effects have been noted by pasture research workers in South America [13].

The flame-thrower, which more or less 'singes' the dead herbage, has been found useful and effective in removing inedible roughage, and has been recommended in some areas.

On the other hand, indiscriminate stocking and grazing will also reduce the plant population and lead to the encroachment of less desirable grasses and weeds. This effect has been noted in Jamaica, where overgrazing of *Panicum maximum* pastures on the coastal plains with long periods of drought has led to the encroachment of *Andropogon pertusus* (Seymour grass), which in some cases has resulted in almost complete annihilation of Silk Guinea grass, thereby seriously reducing the carrying capacity of the pastures. The carrying capacity of well kept *Panicum maximum* pastures ranges from 1–2 acres per beast.

The grass is grown under irrigation to a limited extent in some countries.

*Soilage.*—In peasant-farming areas *Panicum maximum* is grown as a cultivated fodder plant, cut at varying intervals and stall-fed to cattle and other livestock, particularly horses, mules, and donkeys.

*Conservation.*—Very good silage can be made from *P. maximum*; where made it has proved to be a most valuable source of supplementary feed in the dry periods of the year. At present silage-making is confined mostly to dairy-farming districts. It can also be conserved in the form of hay, but this is only on a limited scale at the moment, due chiefly to the erratic nature of rainfall in the tropics, labour problems in the absence of mechanization, and lack of knowledge of suitable methods of haymaking under tropical conditions.

Trials conducted in Jamaica on the possibilities of artificial drying of this grass showed that it could be dried successfully if cut at a leafy stage, but that until cost of production is considerably reduced, it would not be economic at current prices for animal products.

*Grass/legume mixtures.*—One of the major factors influencing grass and animal production in the tropics, is the absence of suitable legumes in pastures. Much work is now in progress in several tropical countries which aims at correcting this deficiency, by establishing grass/legume leys. *Panicum maximum* has been found to grow successfully with *Centrosema pubescens*, *Pueraria phaseoloides*, *Stylosanthes* spp., and *Indigofera endecaphylla*. The *Centrosema pubescens* mixture is reported by Graham [14] to withstand dry conditions and grows well in a wet summer, exhibiting a high degree of palatability.

The persistency of *Stylosanthes* spp. and *Pueraria phaseoloides* entails very good management of the *Panicum maximum* sward. *Indigofera endecaphylla* shows good promise in several areas but reports from Hawaii, Jamaica, and elsewhere have indicated that it may be toxic to cattle if consumed in quantity.

More agronomic research work is needed to devise systems of management aimed at maintaining proper sward-balance in established leys between this grass and companion legumes for a satisfactory period. There is need also to find a wider range of suitable legumes for use in tropical pastures.

*Yield.*—For palatability and yield *P. maximum* ranks high among tropical grasses. A wide range of yields has been reported from different countries due to variability in strains and ecotypes, and varying systems of management under different environmental conditions. Comparison of such figures would be of little value, since some of these yields have been recorded in terms of annual green-matter production without any indication of climatic factors and management practices. A review of these yields will, however, give some indication of the potentialities of the grass.

Jacobson [15], working in the Philippines, recorded an annual yield of 48 t. of green matter per acre. Malayan Department of Agriculture [16] reported annual yields of 13 t. of green matter per acre on sloping land and 16 t. on flat land, after 10 t. per acre of cattle manure was applied. Simpson [17] discussed for Malaya the possibility of yield limit for a particular type of soil stating that 'there would appear to be no correlation between yields of grass and planting distances between limits of 4,840 and 10,890 plants per acre'. Faulkner and Paterson [18], in Trinidad, commented on the very low yield of grasses at Serdang,

Malaya, and suggested that the low yields of grasses tried were 'subnormal and abnormal'. Schofield [19] recorded yields obtained from seven different strains of *P. maximum*. Strains used were the three Australian types, typica, trichoglume, and coloratum, and four Hawaiian. In the first year yields per acre under monthly cutting management ranged from 14·6 t. of green matter (3·42 t. D.M.) to 28·8 t. green matter (7·36 t. D.M.). Two-monthly cutting yields per acre ranged from 16·4 t. to 30·2 t. green matter. Three-monthly cuts ranged from 13·6 to 35·9 t. green matter per acre. No dry-matter yields were reported for the 2- and 3-monthly cuts.

Second-year yields of green matter per acre were given only for the Australian types and varied from 13·8 to 24·6 t. for monthly cuts, and from 9·9 to 21 t. for 2-monthly cuts.

These results show a wide variation in annual yields for strains subjected to similar management and a general trend of increase in yield with age of cut. The figures for individual cuts show a trend of differential seasonal production among some strains subjected to similar management. A basic application of superphosphate (168 lb.), bone-dust (56 lb.), blood (28 lb.), sulphate of ammonia (28 lb.), and sulphate of potash (28 lb.) was made per acre at the beginning of the trial. In the second year fertilizer application was made after each cut, based on the first year's production of each strain. Schofield commented on the second-year results of var. typica, remarking that 'it can be stated that *P. maximum* var. typica under both monthly and two-monthly cutting rotation . . . reacted strongly to fertilizer'.

Motta [20] recorded dry-matter yields per acre per annum of *Panicum maximum* (Silk Guinea) cut on a 4-, 6-, 8-, and 10-weekly basis, ranging from 5·8 t. for 4-weekly cuts to 10 t. for 10-weekly cuts in the first year, and from 5·1 t. for 4-weekly cuts to 5·5 t. for 10-weekly cuts in the second year. There was a gradual increase in total dry-matter yields from 4-weekly cuttings to 10-weekly cuttings in both years, but the increase in the second year was of a lower order than that of the first year. There was a general fall in total yields per acre for all cutting managements in the second year. There was also a big variation in seasonal production. Highest yields were obtained in the rainy periods April to mid-July and September to November. A basic fertilizer application of 6 cwt. sulphate of ammonia per acre in four applications and 2 cwt. muriate of potash per acre in 6-monthly applications were given in both years. No phosphate fertilizer was applied, owing to the high degree of phosphate fixation by the Terra Rossa soil type used for the trial.

Watkins *et al.* [21] of El Salvador, commenting on the behaviour of *Panicum maximum* to 1-, 2-, and 3-monthly cuttings at heights of 4, 8, and 12 in. for each cutting, stated that maximum yields of *Panicum maximum* were obtained at 3-monthly cuttings at a height of 12 in., and that the grass showed a less variable response to time and height of cut than the other grasses tested.

Ellis [22] reported yields obtained from fertilizer trials on different soil types with approximately 8-weekly cutting management, for two

Jamaican strains of *P. maximum* (Silk Guinea and St. Mary's cow grass). Annual dry-matter yields per acre for Silk Guinea ranged from 3 to 5·3 t. and St. Mary's cow grass from 1·5 to 3 t., without the use of fertilizers in both cases. A complete fertilizer dressing (NPK) resulted in an increase in yield of 50 per cent. and more on the soil types studied. A large percentage of this increase was accredited to the effect of nitrogen fertilizer. This effect was also obtained by Ellis and Burrowes [23] working on the response of *Pennisetum purpureum* (Napier grass) and *Panicum maximum* to fertilizer applications.

*Nutrient status.*—*Panicum maximum* follows the normal trend in grasses, showing a decrease of crude protein, expressed as a percentage of dry matter, with age of growth, and a corresponding increase in soluble carbohydrate and crude fibre. From recorded data the crude-protein percentage of the dry matter varies from around 11·5 at the young leafy stage to about 4·0 at the mature stage. Edwards [1] of Kenya gave the following chemical analysis expressed on a dry-matter basis as a guide for assessing its nutrient status:

| *Crude Protein* | *Fat* | *N.F.E.* | *Fibre* | *Ash* |
|---|---|---|---|---|
| 11·3 | 2·8 | 41·0 | 30·2 | 12·7 |

Schofield [24] recorded average crude-protein percentages of dry matter for the seven strains studied ranging from 9·9 to 11·3 for monthly cuts, 5·2 to 6·9 for 2-monthly cuts, and 4·6 to 5·1 for 3-monthly cuts. Figures obtained by Motta [20] and Ellis and Burrowes [23] showed a similar trend, ranging from 11·7 per cent. crude protein in the dry matter for 4-weekly cuts to 4·6 per cent. in dry matter for approximately 3-monthly cuts.

Watkins *et al.* [21] found that the crude protein in the dry matter did not vary with height of cut, but was highest in samples harvested every month.

Henrici [25], working on the contents of phosphorus and calcium in grasses collected in Natal, observed that the *P. maximum* samples collected showed good to very good phosphorus-content. Lower phosphorus figures were obtained on soils of low phosphate status. It was stated that 'for Natal there was no doubt that *Panicum maximum* can be improved by a good soil. Such grasses will most likely benefit by a phosphorus fertilizer.' Figures obtained from the analyses of green and brown leaves of the grass showed that a high percentage of $P_2O_5$ had disappeared in the brown leaves. The position for calcium seemed to have been different, showing very little variation between green and brown leaves. Analyses of dry matter of two samples of *P. maximum* were as follows:

| | *Ash* | $P_2O_5$ | CaO | *C.P.* |
|---|---|---|---|---|
| (1) Green leaves . . | 12·02 | 0·380 | 0·88 | 11·55 |
| Brown leaves . . | 11·42 | 0·148 | 0·92 | 5·21 |
| (2) Green leaves . . | 13·83 | 0·731 | 0·80 | 8·23 |
| Brown leaves . . | 14·52 | 0·283 | 0·70 | 4·42 |

The crude protein in the dry matter showed a great decline in the brown leaves. Schofield [26] also found that the phosphoric-acid content of *Panicum maximum* strains ranged from medium to good, and depended on the stage of maturity; the calcium-content of the strains studied varied considerably. Graham [11] mentioned the possibility of a falling off in phosphate-content of this grass during the dry season, and suggested that the deficiency in the diet could be obviated by providing the stock with phosphate licks.

Although the total dry matter produced increases with age, the quality of the grass declines rapidly. Systems of management should be used that will give good-quality grass together with optimum yields and persistency of sward. This point cannot be overstressed in view of the general absence of pasture legumes in *P. maximum* pastures. Trees of the Leguminosae family that can be of great nutritional value to stock are present in some of these pastures as shade trees for stock, but in most areas their true value has not yet been exploited. However, such trees may prove most useful in the dry periods of the year. Proper rotational grazing with adequate rest periods, the use of inorganic fertilizers and the mowing-machine, will achieve good-quality grass together with high yields over a satisfactory period of years.

*Conclusion.*—*P. maximum* has played and can play a still further part in the expansion of animal production throughout the tropics; but much research is required to find answers to the many problems that present themselves. Some of these are (1) the potential value of existing strains and ecotypes under different environmental conditions both from the fodder- and seed-production aspects; (2) methods of incorporating suitable companion legumes in the pastures; (3) an assessment of the true value of this grass as a soil improver and fertility builder under ley conditions; and (4) the best methods of management and utilization of this grass alone and with pasture legumes over the whole year, and from season to season. The wide range of adaptability, high productivity, and good response to fertilizer application go to make *Panicum maximum* potentially one of the most valuable of grasses in the tropics.

## REFERENCES


1. D. C. Edwards, and A. V. Bogdan, Important Grassland Plants of Kenya. Isaac Pitman & Sons, 1951.
2. Sierra Leone, Dept. of Agric., Pasture and Fodder Plants in Sierra Leone. Agricultural Notes No. 6, 1944.
3. H. E. Warmke, Cytotaxonomic Investigations of some Varieties of *Panicum maximum* and *purpurascens* in Puerto Rico. Agronomy J., 1951, **43**, 143–9.
4. Trinidad and Tobago, Dept. of Agric., Administration Report of the Director of Agriculture for the year 1946. 1948.
5. Brazil Ministerio da Agricultura, Secção de Agrostologia, Pub. No. 6., 1935.
6. C. T. White, The Varieties of Guinea grass (*Panicum maximum*) cultivated in Queensland. Dept. Agric. & Stock, Div. of Plant Indust. (Research), Pamphlet No. 45, 1938.
7. C. W. Winders, Permanent Summer-growing Pasture Grasses, Legumes, &c. Ibid., Pamphlet No. 50, 1937.
8. Division of Pasture Research, Pasture Research in Southern Rhodesia. Progress Report (1945–7). 1948. Bull. No. 1446.

9. H. G. MUNDY *et al.*, Grasses of Agricultural Importance in Southern Rhodesia. Dept. Agric. Salisbury, Rhodesia, Bull. No. 416.
10. GUY PERRIN DE BRICHAMBAUT, Le genre *Panicum*. Les Cahiers de la Recherche agronomique, 1950, **3**, 338–45.
11. T. G. GRAHAM, Grassland Development in Tropical Coastal Areas. Qd. Agric. J., 1946, **63**, 261.
12. R. N. SANDERS, A Report on a Tour of Coastal Queensland and the Tweed River of the Far North Coast of N.S.W. Agric. J. Fiji., 1947, **18**, 63–69.
13. G. M. ROSEVEARE, The Grasslands of Latin America. Imp. Bur. Pastures & Field Crops, 1948. Bull. No. 36.
14. T. G. GRAHAM, Activities of the Bureau of Tropical Agriculture. Qd. Agric. J., 1948, **66**, 69–81.
15. H. O. JACOBSON, Guinea Grass. Philipp. Agric. Rev., 1914, **7**.
16. Malayan Dept. of Agric., Experiments with Guinea grass at the Central Experiment Station, Serdang. Malayan Agric. J., 1938, **26**, 224–57.
17. H. L. SIMPSON, Manurial Experiments with Guinea grass at the Central Experiment Station, Serdang. Ibid., 1940, **28**, 171–6.
18. O. T. FAULKNER, and D. D. PATERSON, The Yield of Perennial Fodder Grasses in Malaya and its Implications. Trop. Agric. (Trinidad), 1942, **19**, 51–53.
19. J. L. SCHOFIELD, The Effects of Season and Frequency of Cutting on the Productivity of Various Grasses under Coastal Conditions in Northern Queensland. Qd. Dept. Agric. and Stock, Grassland Series No. 2, 1944.
20. M. S. MOTTA, Unpublished report on Yield and Protein-content of 14 Grasses cut at intervals of 4, 6, 8, and 10 weeks. Grove Place Agricultural Station, Jamaica.
21. J. M. WATKINS, and MARIO LEWY-VAN SEVEREN, Effect of Frequency and Height of Cutting on Yield, Stand, and Protein-content of some Forages in El Salvador. Agronomy J., 1951, **43**, 291–6.
22. T. O. ELLIS, A Preliminary Survey of the Yields, Composition, and Fertilizer Responses of Fodder Grasses. Dept. Agric. Jamaica, 1950. Bull. No. 41 (N.S.).
23. ——and W. D. BURROWES, Results of Experiments on Yields, Composition, and Responses to Fertilizers of Napier Grass and Guinea Grass in Jamaica. Ibid., Bull. No. 43 (N.S.).
24. J. L. SCHOFIELD, Protein-content and Yield of Grasses in the Wet Tropics as influenced by Seasonal Productivity, Frequency of Cutting, and Species. Qd. Dept. Agric. and Stock, 1945. Bull. No. 26 (N.S.).
25. M. HENRICI, An Investigation of the Content of Phosphorus, Calcium, and Protein of Grasses in the Coastal Region of Natal and Southern Zululand. Union of South Africa Sci. Bull. 1932. No. 115.
26. J. L. SCHOFIELD, Mineral-content and Yield of Grasses in the Wet Tropics as influenced by Seasonal Productivity, Frequency of Cutting, and Species. Qd. Dept. Agric. and Stock, 1946. Bull. No. 28 (N.S.).

(*Received April 22, 1952*)

# FODDER-BEET

## PART III. FEEDING TRIALS WITH DAIRY CATTLE

G. L. BAILEY, M. E. CASTLE, AND A. S. FOOT

*(National Institute for Research in Dairying, University of Reading)*

THE value of fodder-beet as a producer of a large weight of dry matter and soluble carbohydrates per acre has been shown in several recent field trials [1, 2]. As a supplementary food for fattening pigs it has proved to be very satisfactory [3, 4, 5], and vastly superior to mangolds. As the feeding-value of fodder-beet for dairy cattle has, however, received little interest in Great Britain, a series of feeding trials with this relatively new crop has been carried out and these are reported in this paper.

### *Preliminary Trials*

In the first trial, fodder-beet (variety Pajbjerg Rex IX) containing 22 per cent. of dry matter was fed to four Dairy Shorthorn cows throughout March when the animals were being managed under typical winter conditions of feeding and housing. Three cows weighed between 1,000 and 1,200 lb. and the fourth almost 1,700 lb. The four cows had been receiving a ration of hay, grass silage, mangolds, and concentrates, and during the trial the mangold portion of the ration was replaced by fodder-beet. The weight of fodder-beet fed daily was increased from 20 lb. at the beginning of the trial to 60 lb. at the end of the third week, and remained at this level for a further two weeks. When the cows were receiving this weight of beet, the grass silage was withdrawn from the ration. A typical ration was 60 lb. chopped fodder-beet, 10 lb. hay, and 6 lb. of balanced concentrates.

The beet proved to be very palatable and there were no refusals of food even at the highest level of feeding. Throughout the trial the normal decline in the milk yield associated with stage in lactation was recorded and the live-weights of the cows remained practically constant. No visible ill effects on the health of the animals were observed although the consistency of the dung during the period of heavy beet-feeding was much looser than during the early part of the trial.

From this limited trial it appeared that fodder-beet could be fed with safety to milking-cattle and that it was very palatable.

The second trial was conducted in the early autumn to investigate the effect of feeding fodder-beet immediately after lifting to milking-cattle. The beet, variety Pajbjerg Rex X, was pulled, topped, cleaned, and fingered, and fed direct from the field. Its dry-matter content was 18 per cent. Feeding began on September 26 when the cattle were out at grass by day but kept in at night. Two Shorthorn cows giving 2 and 3 gals. of milk daily were fed 40 lb. of the beet for four days. This quantity was consumed readily and the cattle milked normally.

For two further periods of 10 days in mid-October and early November, 33 lb. of fresh-pulled beet was fed daily to ten milking-cows to

[Empire Journ. of Exper. Agric., Vol. 21, No. 81, 1953.]

supplement an all-grass diet. Ample grass was available for grazing, yet the beet was consumed with great avidity. The milk yield of the individual cows varied widely, but it is of interest that daily yields of 2½ to 3 gals. were maintained on beet and grass only at this late season of the year.

One cow, after 4 days of beet-feeding, was slightly blown, and her milk yield fell, but there was no clear-cut evidence that this condition was the result of the beet-feeding. The animal recovered normally, beet was fed for the remainder of the trial, and no further digestive troubles occurred.

The fodder-beet had an approximate sugar-content of 12·6 per cent., and the percentage composition of the dry matter was: crude protein 6·4, ether-extract 0·3, soluble carbohydrate 80·8, crude fibre 5·1, and ash 7·4.

In this particular trial using fodder-beet grown under conditions of moderate fertilizer treatment no detrimental effect on the health of the cattle was observed, and the beet proved to be a most palatable food.

The third preliminary trial took place in early March, and was designed to investigate the effects of feeding exceptionally heavy rations of fodder-beet upon the health and milk yield of dairy cows. Two Shorthorn cows weighing 12 cwt. and two Friesians of almost 13 cwt. which had been receiving fodder-beet in their rations for the previous 2 weeks were fed rations containing up to 100 lb. of beet (variety Hunsballe) per day. The beet had 19·9 per cent. dry matter, and a typical ration was 6 lb. hay, 90 lb. fodder-beet, and 19 lb. balanced concentrates. The beet, which was chopped, was fed after each milking. The quantities used were intentionally kept well above those likely to be fed in normal farm practice.

The largest weight of fodder-beet eaten in 1 day was 98 lb., but although the beet appeared palatable to the stock, refusals were recorded at the top level of feeding, and the average weight consumed by the four cows over the trial period was 80 lb. per day. No digestive disturbances were recorded, and the dung of the animals was not unduly loose compared with that of similar animals eating more normal rations. The two Friesians in the trial both averaged 3½ gals. of milk a day.

This trial was conducted for only 1 week, but, as indicated by these short-term results, there seemed to be no valid reasons from the nutritive point of view, against the feeding of rations containing up to 80 lb. of high-dry-matter fodder-beet to dairy cattle weighing from 12 to 13 cwt.

### *Comparative Feeding Trial with Mangolds*

*Method.*—This more comprehensive trial was designed to compare the relative feeding-value for milk production of fodder-beet and mangolds. The trial was carried out during February and early March when the animals had access to bare pasture only and were fed indoors twice a day.

Twelve cows at varying stages of lactation were used in the trial, and were rationed according to their milk yield and live-weight. There

were two experimental feeding-periods of 14 days. In period 1 all the cows were given balanced rations consisting of mangolds (variety Yellow Globe), lucerne hay, and concentrates, and in period 2 of fodder-beet (variety Hunsballe), lucerne hay, and concentrates. The hay and concentrates were of the same batches throughout periods 1 and 2. Details of the chemical composition of the foods are given in Table 1. The proportions of the different foods making up the whole rations were made to vary as much as possible, and details of these are given in Table 2 together with data concerning the experimental cows. The animals were weighed weekly, and all food and milk daily.

TABLE 1. *Composition of the Foods Used*

| | *Lucerne hay* | *Mangold (Yellow Globe)* | *Fodder-beet (Hunsballe)* | *Concentrate* mixture* |
|---|---|---|---|---|
| Dry matter (%) | 82·9 | 11·1 | 19·9 | 85·7 |
| *Percentage of the dry matter* | | | | |
| Crude protein | 13·3 | 9·1 | 9·1 | 21·8 |
| Ether-extract | 2·0 | 0·4 | 0·3 | 3·2 |
| Soluble carbohydrates | 40·5 | 70·8 | 73·6 | 60·2 |
| Fibre | 35·9 | 6·0 | 5·1 | 9·2 |
| Ash | 8·3 | 13·7 | 11·9 | 5·6 |

* The concentrate mixture was 1 part bran, 1 part groundnut cake, and 3 parts dredge corn.

For analysing the results, the mean daily milk yields for the last 5 days of each of the two 14-day periods were used. The data for each period were considered separately at first, and for each animal the sum of her food-intake was equated against her milk yield and maintenance requirements according to the general formula:

Milk yield (lb.) + [Live-weight (lb.)]$^{\frac{3}{4}}_{b_1}$ = Hay (lb.)$_{b_2}$ + Fodder-beet or Mangolds (lb.)$_{b_3}$ + Concentrates (lb.)$_{b_4}$ where $b_1$, $b_2$, $b_3$, and $b_4$ are unknown coefficients.

The twelve formulae in this form produced from each feeding-period were reduced to four by the method outlined by Wood & Capstick [6]; and the coefficients were determined by the normal methods for solving simultaneous equations.

The results obtained for the relative feeding-values naturally depend on the mathematical treatment of the data. The most important source of variation is the factor involving the live-weight of the animals. There are good theoretical reasons for using the $\frac{3}{4}$ power of the live-weight, for this is proportional to basal metabolism, and is a measure of the net energy required to carry on the vital functions. It is probably also proportional to the energy used in normal physical effort, but it should be remembered that this part of the factor is subject to wide variation, and it is only when the proportion is approximately the same for each

TABLE 2. *Details of the Experimental Cows, Rations, and Milk Yields*

| Cow No. | Breed* | Number of weeks from calving to experiment | Period 1 | | | | | Period 2 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Mean live-weight (lb.) | Daily ration (lb.) | | | Average daily milk yield (lb.) | Mean live-weight (lb.) | Daily ration (lb.) | | | Average daily milk yield (lb.) |
| | | | | Hay | Man-golds | Concen-trates | | | Hay | Fodder-beet | Concen-trates | |
| 1 | S | 26 | 1,118 | 6 | 60 | 7 | 12·4 | 1,172 | 7 | 36 | 7 | 11·2 |
| 2 | S | 26 | 1,214 | 16 | 30 | 5 | 13·1 | 1,236 | 17 | 18 | 5 | 10·2 |
| 3 | S | 16 | 1,328 | 16 | 40 | 8 | 20·2 | 1,366 | 17 | 24 | 8 | 22·3 |
| 4 | S | 24 | 1,230 | 10 | 50 | 6 | 15·1 | 1,282 | 11 | 30 | 6 | 14·7 |
| 5 | S | 26 | 1,062 | 15 | 20 | 5 | 14·1 | 1,082 | 16 | 12 | 5 | 14·2 |
| 6 | S | 18 | 1,408 | 13 | 40 | 14 | 32·5 | 1,432 | 14 | 24 | 14 | 32·0 |
| 7 | G | 23 | 1,132 | 12 | 40 | 6 | 14·0 | 1,172 | 13 | 24 | 6 | 13·7 |
| 8 | G | 58 | 972 | 12 | 30 | 5 | 15·5 | 998 | 13 | 18 | 5 | 12·5 |
| 9 | F | 24 | 1,352 | 8 | 60 | 7 | 16·1 | 1,362 | 9 | 36 | 7 | 16·7 |
| 10 | F | 36 | 1,224 | 10 | 20 | 10 | 14·2 | 1,250 | 11 | 12 | 10 | 13·5 |
| 11 | F | 12 | 1,362 | 6 | 60 | 15 | 35·1 | 1,360 | 7 | 36 | 15 | 32·8 |
| 12 | F | 6 | 1,370 | 8 | 50 | 18 | 37·2 | 1,394 | 9 | 30 | 18 | 38·7 |

* S = Shorthorn, G = Guernsey, F = Friesian.

animal that the use of a single factor for both basal metabolism and normal physical effort is justified.

The live-weight gain is another factor which should be considered where high precision is required. In this study live-weight changes have been ignored owing to the inadequacy of the two weighings made during each feeding-period.

*Results*

There were no refusals of food throughout the trial, and the values of the coefficients obtained from the data in Table 2 are given in Table 3.

As the same concentrates were fed throughout the two feeding-periods, the small difference between the coefficients (2·537 and 2·690)

TABLE 3. *Coefficients obtained in Feeding-trial*

| | *Period 1* | *Period 2* |
|---|---|---|
| Concentrates ($b_4$) . . | $+2{\cdot}537 \pm 0{\cdot}263$ | $+2{\cdot}690 \pm 0{\cdot}187$ |
| Hay ($b_2$) . . . | $+1{\cdot}343 \pm 0{\cdot}405$ | $+1{\cdot}559 \pm 0{\cdot}291$ |
| Mangolds ($b_3$). . . | $+0{\cdot}284 \pm 0{\cdot}098$ | |
| Fodder-beet ($b_3$) . . | | $+0{\cdot}573 \pm 0{\cdot}116$ |
| Live-weight $\frac{1}{4}$($b_1$) . . | $-0{\cdot}255 \pm 0{\cdot}085$ | $-0{\cdot}330 \pm 0{\cdot}063$ |

for this food is probably due to changes in the maintenance requirements of the animals and in their mean plane of nutrition, and when these coefficients are reduced to unity by calculating ratios, a direct comparison between the feeding-value of the mangolds and the fodder-beet can be made:

Period 1, ratio A, mangolds: concentrates = 0·1119 : 1
Period 2, ratio B, fodder-beet: concentrates = 0·2128 : 1
Ratio fodder-beet: mangolds = ratio B: ratio A = 1·901 : 1

This indicates that the feeding-value for milk production of the fodder-beet was 1·901 times that of the mangolds, or expressed alternatively, 1·0 lb. of fodder-beet was equal in feeding-value to 1·901 lb. of mangolds. The dry-matter contents of the mangold and fodder-beet were 11·1 and 19·9 per cent. respectively, and when the two foods are considered on a dry-matter basis, the ratio fodder-beet: mangold equals 1·062 : 1. This still shows a very small advantage in favour of the fodder-beet.

An alternative method of calculating the ratio would have been to use the coefficients for the hay for standardization instead of those for the concentrates. It was, however, considered that the concentrates were less liable to variation in composition than the hay, so the coefficients for the concentrates were given preference. It is noteworthy that the high feeding-value of the hay as indicated by the chemical analysis, is reflected in the values of the calculated coefficients; it would appear from these that the hay had rather more than half the feeding-value of the concentrates.

An approximate check on the ratio between the feeding-value of the fodder-beet and the mangolds may be made by comparing the calculated starch-equivalent values of the two foods. Using the digestibility coefficients given by Woodman [7], the chemical analyses in Table 1, and with the sugar-content of the mangolds assessed at 4 per cent. and that of the fodder-beet at 12 per cent., the ratio of the starch-equivalent values was, fodder-beet: mangold:: 1·908: 1. The starch equivalent of the fodder-beet is estimated to be approximately 10.

*Discussion*

When considering the above trials as a whole it is evident that the varieties of Danish fodder-beet used were highly palatable to the cattle, and proved to be a useful carbohydrate food. The fodder sugar-beet, Pajbjerg Rex, and the sugar-beet for fodder, Hunsballe, were both fed, and were found to be equally safe, even when fed in quantities far in excess of normal. The rations containing 80 lb. of fodder-beet per day were eagerly consumed but it would seem that this is about the maximum quantity that can be fed if a balanced ration is to be achieved. Although all root crops must be regarded as 'watered' carbohydrate concentrates, fodder-beet does offer a material advantage compared with the mangold because of its more concentrated form. For all practical purposes the feeding-value of the dry matter of the mangold and fodder-beet appear about equal, but owing to the differences in the dry-matter content, 1 lb. of fodder-beet is equal in feeding-value to 1·9 lb. of mangold. This indicates a considerable economy in the cost of cleaning, pulping, and handling the root ration of the dairy cow, and merits further consideration of the fodder-beet as a crop for the dairy farm.

If, as the results of these trials suggest, fodder-beet does not require a period of maturation before it can be fed to cattle, it would appear that this would allow both autumn and spring feeding, and so lead to a simplification in winter-feeding plans which would not be possible in the case of mangolds.

The sample of fodder-beet used in the main feeding-trial had a starch equivalent estimated to be 10. This is lower than the value calculated from the analysis of sample roots from the plots given in a previous paper [2], and is attributable to the lower dry-matter content of the roots, and their lower content of soluble carbohydrates. Roots with 20–22 per cent. of dry matter would appear to have starch-equivalent values of 10–13 per cent., but, as with any other feeding-stuffs, these figures should be used only as a guide to feeding the roots in practice. Steensberg [8] has calculated from feeding-trials with dairy cattle that 1·1 kg. of fodder-beet dry matter is equivalent to 1·0 kg. of barley. This was for a sample of beet containing 84·3 per cent. soluble carbohydrates in the dry matter (a high value), and when calculated for a root of 19·9 per cent. dry-matter content gives a starch equivalent of 13. A protein equivalent of 0·7 has been estimated from the results in the present trial.

Owing to the superiority of fodder-beet over mangold as a producer

of nutrients [2], and the fact that this crop can produce three or four times the output of starch equivalent per acre as an average crop of oats or barley, there would seem to be a useful place for the fodder-beet on the intensive-managed dairy farm where self-sufficiency is the aim.

*Summary*

1. Details are given of four feeding-trials with dairy cattle to investigate the feeding-value of Danish fodder-beet.

2. The fodder-beet was found to be a palatable food. It gave satisfactory results when fed immediately after pulling in September under our particular conditions.

3. Daily rations including up to 98 lb. of fodder-beet were fed successfully to milking-animals.

4. In the main feeding experiment 1 lb. of fodder-beet (dry matter 19·9 per cent.) was equal in feeding value to 1·9 lb. of mangold (dry matter 11·1 per cent.). On a dry-matter basis 1 lb. of fodder-beet was equal to 1·062 lb. of mangold.

5. The starch equivalent of the fodder-beet was estimated to be 10.

6. The feeding of fodder-beet, and its advantages as compared with mangolds are discussed.

*Acknowledgements.*—The authors wish to thank Dr. S. J. Rowland and Mr. A. W. Wagstaff for the analysis of the samples; also Mr. C. Line and Mr. R. J. Lewington for valuable assistance with the feeding-trials.

REFERENCES

1. M. E. Castle, A. S. Foot, and S. J. Rowland, Empire J. Expt. Agric., 1952, **20**, 1.
2. —— —— —— ibid. 316.
3. R. Braude and K. G. Mitchell, Agriculture, 1949, **56**, 369.
4. A. C. Dunkin and M. M. Cooper, ibid. 364.
5. A. K. M. Meiklejohn, Scot. J. Agric., 1951, **31**, 93.
6. T. B. Wood and J. W. Capstick, J. Agric. Sci., 1928, **18**, 486.
7. H. E. Woodman, Rations for Livestock, 1948, Min. Agric. Bull. No. 48, p. 107.
8. V. Steensberg, Forsøgslab. København, Beretn., 1948, No. 231, 68.

(*Received August 7, 1952*)

*Postscript.*—During the late months of 1952 a number of reports of digestive disorder in cattle receiving fodder-beet have come to hand. The condition has been reproduced experimentally using weights of fodder-beet comparable with those reported above and hitherto found satisfactory. The reason for the difference in results on fodder-beet feeding during this year and previous years has not yet been established.

*December, 1952*

# REFLECTIONS ON THE WORLD NITROGEN POSITION

F. C. O. SPEYER

In attempting to answer the Editor's ingenuous question: 'How much nitrogen may we expect to get for agriculture in the years to come?' one must begin by presenting a brief summary of the available information about the nitrogen industry and then attempt to outline some of the more fundamental problems. The figures presented should all be regarded as estimates.

*Present production and consumption.*—The discovery and development of the ammonia-synthesis process has given mankind access to the practically unlimited supply of nitrogen in the atmosphere. This nitrogen can be combined with hydrogen to form ammonia under a good many conditions favourable to modern industry. A cheap source of energy is required in the form of coal, oil, natural gas or hydro-electric power, and the hydrogen can usually be made by suitable use of any of these. Steel is also required for the plant itself.

As a rough guide, it may be assumed that for the production of nitrogen in the form of nitrogen fertilizer one ton of steel is required for each ton/year of installed nitrogen capacity, and that the energy equivalent of about 5 tons of coal is needed for each ton N produced. Thus a plant with a capacity of 100,000 tons/year N will require 100,000 tons of steel, and the energy equivalent of about 500,000 tons of coal for each 100,000 tons N produced.

There are wide variations in both capital and running costs. The capital required is likely to be as high as £200 per ton/year of nitrogen and may even be higher, as it will depend on the relative advantages of the site selected. Production costs per unit of nitrogen tend to be in inverse proportion to volume of output and also vary considerably according to the form of finished fertilizer produced, e.g. anhydrous ammonia, ammonium nitrate, calcium nitrate, urea, or ammonium sulphate for which an economic source of sulphur is also needed.

The other processes or sources making an important contribution to the supply of nitrogen fertilizers are the calcium cyanamide process, which uses electric power in conjunction with the production of calcium carbide: coal-distillation processes recovering ammonia as a by-product, which is then combined with sulphuric acid to form ammonium sulphate: and Chilean nitrate of soda.

In 1950 the total installed world capacity of all these industries was equivalent to about 5·5 million metric tons nitrogen (MTN) per annum and is now about 6·4 m. MTN. The individual contributions to the total are, in percentages, ammonia synthesis 78, cyanamide 8·6, by-product ammonia 8·5, and Chile nitrate of soda 4·9. There are important plans for expansion and if all presently known projects are carried out, world-production capacity will rise to 7·5 m. MTN by 1954 and to 8·1 m. MTN a year or two later.

Turning now to consumption, the nitrogen industry records its

[Empire Journ. of Exper. Agric., Vol. 21, No. 81, 1952.]

figures under the headings agriculture and industry. Whilst in recent years industry has accounted for 25 per cent. of the total N consumption in U.S.A. and Canada, the proportion in Europe and Asia has been under 10 per cent. The world average for the last 5 years is about 14·5 per cent. This proportion will diminish as agricultural consumption grows in North America and elsewhere. It may reasonably be assumed that at least 85 per cent. of the projected increase in production mentioned above will be available for agriculture.

In the present century during the periods of normal conditions (excluding wars and depressions) agricultural consumption of nitrogen had increased at rates varying from 7·8 to 11·4 per cent. cumulative per annum. Since 1947 the cumulative annual increase has been at the rate of about 10 per cent. If this continues, world agriculture will require about 7·2 m. MTN by 1956–7 and capacity will have to be raised to over 8·5 m. tons to meet the needs of both agriculture and industry.

This conclusion is supported by recent statements made by Mr. C. F. Brannan and other representatives of the U.S. Department of Agriculture who have emphasized the importance of nitrogen in increasing crop yields and are advocating the reversal of the traditional U.S. formula of 1 unit N to 2 units of $P_2O_5$ in much of the cultivated area of the U.S. It may be added that in recent years both scientific and practical farming experience in many other countries has been showing that the ratio of nitrogen to phosphates used in conventional practice has been far too low and that much heavier dressings of nitrogen can be safely and profitably used. It should be remembered that non-leguminous crops take up about three times as much nitrogen as phosphate ($P_2O_5$) from the soil.

In the United Kingdom production of nitrogen has exceeded home consumption for more than half a century and the surplus has been used to build up large and valuable markets in Commonwealth and other countries. Home consumption for agriculture has risen from 60,000 MTN in 1938–9 to nearly 210,000 tons in 1951–2. To meet the needs of the Government's present plan for agricultural expansion a further 100,000 tons will be required. For so long as British taxation continues to prevent producers making adequate provision for depreciation of capital assets it seems unlikely that industry in this country will expand its investment in nitrogen. If there is no increase in production, recourse will have to be made to stopping exports. Even this will provide only about 70 per cent. of what is needed, and the balance will have to be sought in imports.

*The future.*—We may perhaps conclude from the above picture that the world agricultural demand for nitrogen during the next 5 years is likely to be met unless rearmament prevents the additional capacity being completed in time.

What criteria can we apply for estimating requirements in the more distant future?

The first two are obviously trend of population and, if we look to agriculture as our mainstay, area of land capable of giving a massive response to man's efforts.

Mr. Colin Clark pointed out in *Lloyds Bank Review* for April 1952 that (excluding China where population has probably been stationary for the last hundred years because death- and birth-rates have been equal) the world population was rising at the rate of 0·95 per cent. per annum from 1850 to 1913. In 1920—mainly due to the typhus and influenza epidemics—it was the same as in 1913. But from 1935 onwards gross and net reproduction rates have been increasing owing to increased average size of family and earlier age of marriage. He states that 'While England, Denmark, and Sweden appear to be adhering to the two-child average family of the 1930's, the figure in Scotland and Australia is 2½ and the three-child average now prevails in the United States, France, Finland, Italy, Netherlands, Norway, New Zealand, Switzerland, and the white population of South Africa.' Canada, Spain, and Portugal show a four-child average. This is similar to the figures which now show a descending tendency in Oriental countries including India, Japan, and Russia, where the mortality is far higher.

If the three-child rate continues in America and most western European countries (except England) and allowance is made of 7 per cent. for premature death and 10 per cent. for the unmarried, then 2 parents in one generation will be followed by 2·5 parents in the next and, owing to earlier marriages, the generations come round more frequently. The effect is that each generation is 25 per cent. larger than the last, and generations come round on the average every 25 years. This means that the United States and western European countries have apparently settled down to a rate of natural increase—apart from immigration—of 1 per cent. per annum, a figure of the same order as applies in India. In Canada and Spain the long-term rate of natural increase now probably exceeds that of the most rapidly increasing Oriental countries such as Ceylon and Malaya or Latin America.

Mr. Clark concludes that taking all these factors into account world population will be increasing at the rate of 1¼ per cent. per annum between 1952 and 1970. If we take world population in 1952 as 2,400 m. and apply this rate, we get 3,000 m. by 1970. If we are less cautious than Mr. Clark and assume a continuance of this rate of progression, we get 4,500 m. by A.D. 2000. Now in *Four Thousand Million Mouths*, F. Yates estimates that 1 ton of nitrogen in fertilizer form produces on an average 10 tons of starch-equivalent in the form of extra food crops and that 5 cwt. of starch-equivalent suffices to feed one person for a year. This is more than Eastern peoples are getting today. However, on this basis 1 ton N applied to food crops can produce extra food sufficient to nourish forty persons for one year. Assuming for the purpose of the argument that more nitrogen for agriculture is the chief means of obtaining the extra food required, supplies for world agriculture would have to be increased from 4½ m. tons in 1952 to over 57 m. tons by the end of the century. The intermediate steps in this progression are set out in the footnote (p. 54) together with comparable figures obtained by a different calculus.

The second criterion was area of land. In his presidential address to the British Association in 1949 Sir E. John Russell estimated that at

present some 3,000 to 4,000 m. acres are used for growing crops in the world and that 85 to 90 per cent. of this area is used for food production. He also estimated that 11 milliard acres—about 31 per cent. of the earth's surface—are climatically suited to crop growth but that much of this is impracticable for cultivation. Pressure of population will probably increase the area of land cultivated to 5,000 m. acres by the end of this century but, as much of this would be too dry to respond to nitrogen, Dr. H. L. Richardson (private communication) suggests 2,500 m. acres as the area likely to give an economic response.

What average rate of application per acre should we assume? In a recent article in *Die Chemische Industrie*, Dr. H. K. von Borries of Bochum has compared the rates of application of nitrogen in nine European countries in 1950–1 with the rates used over 1937–9. These rates are obtained by dividing the total tonnage of nitrogen delivered for agricultural use in each country by the acreage of agricultural land, excluding rough grazings.

I have arranged the countries in two groups. The figures are expressed in kilograms N per hectare (kg./ha.) for both periods with the equivalent for 1950–1 in cwt. per acre of a fertilizer containing 20 per cent nitrogen. The figures show a very large increase in use of nitrogen in most of the countries.

TABLE 1. *Fertilizer Nitrogen Consumption*

| *First group* | *Netherlands* | *Belgium* | *Norway* | *W. Germany* | *Denmark* |
|---|---|---|---|---|---|
| 1937–9 kg./ha. . | 37·2 | 31·3 | 9·6 | 21·3 | 11·8 |
| 1950–1 kg./ha. . | 68·3 | 46·4 | 38·1 | 26·1 | 22·5 |
| 1950–1 cwt./acre 20% N fertilizer | 2·72 | 1·85 | 1·52 | 1·06 | 0·9 |

| *Second group* | *U.K.* | *France* | *Italy* | *Austria* |
|---|---|---|---|---|
| 1937–9 kg./ha. . . . . | 5·1 | 7·1 | 5·5 | 3·6 |
| 1950–1 kg./ha. . . . . | 16·9 | 9·7 | 8·0 | 7·4 |
| 1950–1 cwt./acre 20% N fertilizer . | 0·68 | 0·39 | 0·32 | 0·29 |

Table 2 shows the total acreage and tonnage for 1950–1 and the weighted average rate of application for each group:

TABLE 2

| | *Tons 2,240 lb. Nitrogen* | *Acres 000* | *cwt./20% N.F. per acre* |
|---|---|---|---|
| First group . . . . | 695,169 | 54,048 | 1·286 |
| Second group . . . . | 631,567 | 151,093 | 0·418 |
| Total . . . . . | 1,326,736 | 205,141 | 0·647 |

Although the first group, which includes some of the most intensively cultivated land in the world, shows an average use of about 1¼ cwt./acre of 20 per cent. N fertilizer, the rate for the second group with nearly three times the acreage is only about one-third of this. The general average for the whole 205 m. acres is under ⅔ cwt. per acre.

If we divide the successive nitrogen totals, which emerge from the application of the 'Yates formula' to the population curve, by 2,500 m. acres we get the following picture (Table 3):

TABLE 3

| *Year* | *MTN millions* | *Average rate application cwt./acre 20% N.F.* | *Corresponding with 1950–1 rates for:* |
|---|---|---|---|
| 1970 | 19·5 | 0·76 | U.K. and Denmark |
| 1990 | 44·5 | 1·75 | Belgium |
| 2000 | 57·0 | 2·24 | Netherlands |

I am well aware that the foregoing presentation and analysis omits many factors, and that the best that can be said for part of the argument is that a ***reductio ad absurdum*** sometimes leads to the discovery of truth.

The logical conclusion of the argument is that the world will require over 50 m. tons of nitrogen per annum by the end of the present century. What grounds are there for expecting that such a quantity could and would be used?

Although nitrogen used in suitable conditions is the most important single factor in increasing food production from the land, the other major and minor elements have their share. There will be improvements in cultivation, irrigation, crop rotations, and crop varieties although genetic improvements in plants are likely to increase their requirements of nitrogen. Although the control of weeds, pests, and diseases will reduce losses, we are warned that improved agricultural practice may encourage the multiplication of such pests.

In the background—or perhaps I should say the foreground—lies the fundamental difficulty of organizing agricultural production.

Great improvement in the quality and numbers of mechanical aids to farming has taken place in recent years, but only in comparatively few countries.

In Britain the costs of fertilizers, implements, insecticides, transport, and merchanting add up to nearly half of gross farm-output. The considerable increase in gross product has greatly benefited consumers, but net income per person engaged in agriculture is increasing at only about 1 per cent. per annum, as against 3 per cent. per annum increase in gross product per head. Hence the farmers' demand for higher prices. But the answer to this must be a call for yet higher output per acre from farmers at the lower end of the scale of efficiency. This can be achieved by the use of more nitrogen in conjunction with better management and organization. The same factors appear to be at work in the U.S.A., but in many other parts of the '2,500 m. acres' the necessary organization for high production will be lacking and the use of nitrogen restricted. It is impossible to predict today whether the higher rates of application brought out in the last table can be achieved over so wide an area.

Expansion of the production of synthetic nitrogen, even on the full

scale suggested by the foregoing calculations, should not present any insuperable difficulty for the 'Free World' in respect of steel or sources of energy, if the expansion is spread over a period of half a century. But before embarking on further large investment in the production of nitrogen, industry will want to be satisfied that the labour, materials, and energy required could not be put to better economic use if applied for increasing the production of food and fodder by other means.

For example, in the recent B.B.C. talks on 'Research for Plenty', Mr. Michael Graham stressed the potentialities of the seas and claimed that present world fish-production of 20 m. tons per annum could be doubled or quadrupled if the industry was properly organized. In this particular case nitrogen fertilizers might play a part in increasing the growth of the marine plants on which fish feed. Experiments sponsored by Edinburgh University and carried out in a small loch have demonstrated the response of the plants to N by the increase in weight of the fish, but no practicable means has yet been suggested for applying this method economically to the high seas or even to large lochs. There are also the so-called 'unconventional methods of food production', which are now the subject of much research in this and other countries.

The following table sets out the decennial steps in the above 'population' and 'Yates formula' curves together with those in a comparable curve based on the fact that world nitrogen consumption in agriculture increased by 6 per cent. per annum cumulative during the first half of this century. The figures in line 4 show the tonnage included in those in line 2 for N consumption in U.S.S.R. and Iron Curtain countries in Europe. No figures are available for U.S.S.R. consumption in Asia. All figures in table = millions.

| | *1952* | *1960* | *1970* | *1980* | *1990* | *2000* |
|---|---|---|---|---|---|---|
| 1. Est. world population . . | 2,400 | 2,600 | 3,000 | 3,500 | 4,000 | 4,500 |
| 2. N reqt. on 'Yates formula' MTN . . . . | 4·5 | 9·5 | 19·5 | 32·0 | 44·5 | 57·0 |
| 3. N reqt. on 6% curve MTN | 4·5 | 7·2 | 12·9 | 23·0 | 41·1 | 73·7 |
| 4. USSR & ICC Europe, basis 13·5% of line 2 . . | 0·6 | 1·3 | 2·6 | 4·3 | 6·1 | 7·7 |

*Acknowledgements.*—In acknowledging the debt I owe to many friends for help in compiling this article, I wish to offer special thanks to Dr. H. L. Richardson. Responsibility for the conclusions reached rests solely with me.

(*Received October 31, 1952*)

# THE GENERAL LIFE AND PRODUCTION STATISTICS OF THE SINHALA CATTLE OF CEYLON

P. MAHADEVAN

*(Department of Agriculture, Peradeniya, Ceylon)*

THE Sinhala cattle, which are characterized by their small size and stature and by the relatively poor development of hump and dewlap as compared with most other tropical and subtropical cattle, form the bulk of the cattle population of Ceylon. The fragmentary evidence available as regards their origin [1] suggests that they are part of the remnants of a primitive breed which at one time populated southern Asia, but which was later displaced by the larger forms brought in by human invaders. Isolation and the relative absence of large-scale importations of other stock have helped to perpetuate these cattle in Ceylon.

*Source of data.*—The material for this study, which covers over 600 head of stock, was obtained from a Government herd of Sinhala cattle situated at Karagoda Uyangoda in the southern Province of Ceylon. The farm lies approximately 6° north of the Equator and has an average monthly temperature ranging from about 78° to 82° F. The average annual rainfall over the last 14 years was 93 in.; of this, 24 in. was received during October and November and 12 in. in May, which together constitute two-fifths of the total rainfall. The rest of the rainfall was fairly evenly distributed through the remaining months of the year, but January and February often tended to be relatively dry months. The herd under consideration was started in 1937–8 on a total area of 107 acres. Local cattle of the black Sinhala type were purchased from different parts of the country and maintained on this farm in an attempt to determine the milch and draught potentialities of these animals. At the inception, only 2 stud bulls and 17 cows were purchased; but, during the years 1939–42, 22 more animals were bought in, and the present herd consisting of about 125 head of cattle has been built up almost entirely from these 41 animals, very little outside blood having been introduced into the herd during the 15 years of its existence.

*Life statistics.*—The average birth-weight of the Sinhala cattle on the basis of the present data was found to be $31 \pm 0{\cdot}3$ lb. for males and $29 \pm 0{\cdot}3$ lb. for females. Calves from heifers generally averaged 2 lb. less at birth than calves from older cows. At maturity, the average weight of males was found to be $566 \pm 55$ lb. and that of females $403 \pm 6$ lb. Generally, the bulls have been run with the cows, and the heifers were put to the bull when they reached a live-weight of about 330 lb. In consequence, the average age at first calving has been $42{\cdot}4 \pm 0{\cdot}4$ months. It seems reasonable to assume on the basis of experimental work now in progress on this herd that if the rearing of calves were given greater attention and the heifers brought to a good condition of flesh early in life, a late first-calving could have been avoided. The early maturity work that is now being conducted supports the view that by good feeding

[Empire Journ. of Exper. Agric., Vol. 21, No. 81, 1952.]

during the first 6 to 8 months of life, Sinhala heifers could be served when they are about 18 months of age. The chief advantage of an early first calving is that it would decrease the average interval between generations and thereby tend to increase the annual rate of genetic improvement.

Regularity of calvings has been a noteworthy feature of the Karagoda Uyangoda herd. The freedom from reproductive disturbances which this reflects seems to be characteristic of the Sinhala cattle. It appears likely that this regularity is due in large measure to the low milk yield of the cows: a point which we hope to verify when more data accumulate by a study of the genetic correlation between fertility and yield. Be it as it may, the average calving interval of 355 days for the first 14 years of existence of this farm is one of the lowest recorded for any herd of cattle.

The length of dry period, however, was exceptionally long, and averaged $122 \pm 2{\cdot}9$ days. This means that the length of lactation was only about 233 days. If the latter could be taken as a measure of persistency of yield, it would indicate that the persistency of the Sinhala cattle is very low. This is confirmed by Fig. 1, which shows the shape of the lactation curve for first, second, and later calvers separately, and which is based on over fifty lactations for each group. It has been suggested that one of the methods by which the length of lactation could be increased is 'by selecting for breeding the cows with the longer lactation records' [2]. It is, however, not possible to subscribe to this view because the repeatability of lactation lengths in this herd is low and not significant ($r = +0{\cdot}12$).

It was found that the coefficient of variation of lactation length in this herd was 0·22. The number of lactations ending before 200 days was as high as 25 per cent., which is very much in excess of the corresponding figure of under 5 per cent. for European conditions.

The average length of productive herd life at Karagoda Uyangoda worked out at around five lactations; the average length of *total* productive life may, however, have been higher, as it is known that some of the animals sold from the herd continued their milking-life in other herds.

There seems to have been no well-defined policy as regards breeding. Very little voluntary culling of heifers has been carried out, but a consistent attempt appears to have been made to breed bulls from the better cows. This is reflected in the almost negligible selection differentials for dams of cows and the high selection differentials for dams of bulls. But the genetic advantages gained by the good selection of bulls have been offset to a considerable extent by the late age at which bulls were used for service. The average age of bulls at first service was 56 months, whilst the lowest age was as high as 40 months. As the criterion of the efficiency of any breeding programme is the improvement per year rather than per generation [3], it is evident that, for a sound breeding policy, bulls should be used at as early an age as possible so as to minimize the interval between generations.

Since its inception, the Karagoda Uyangoda herd has been treated

more or less as a closed one, and in consequence the intensity of inbreeding has risen for heifers and bull calves born in recent years to an average of 15 per cent. The effect of the inbreeding on the birth-weight of calves was studied by computing the intra-sire regression of progeny birth-weight on dam's inbreeding after correcting for differences due to sex of calves and differences due to lactation number of

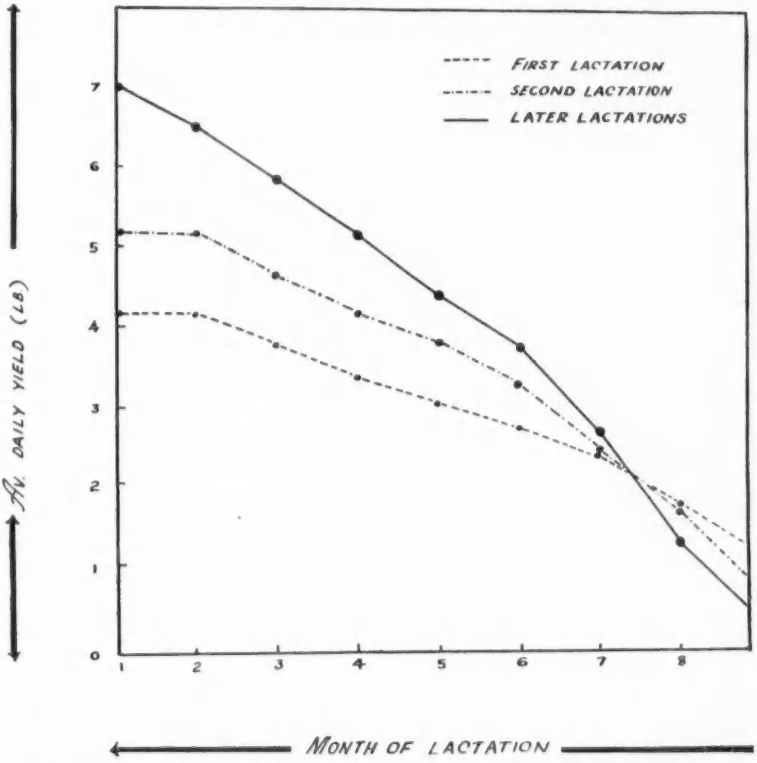



FIG 1. Shape of the lactation curve of first, second, and later calvers.

dam. The regression value of −0·03 lb. for each degree of inbreeding that was obtained, was, however, not significant. It was not possible to determine the effect of inbreeding on production in this herd, because most of the animals with high inbreeding-coefficients have not come into production as yet.

*Production statistics.*—Perhaps one of the most characteristic production traits of the Sinhala cattle is the refusal of the dams to let down their milk if the calves are not allowed to suckle for some time at each milking. Repeated attempts with Sinhala heifers and cows to wean their calves at birth have hitherto not been successful. This is in striking

contrast to the success that has been achieved in weaning calves of other Asiatic breeds of cattle in Ceylon, and it is bound to be a great handicap if the Sinhala cattle are to be developed to any great extent as a pure breed for milk production.

The average milk yield per lactation in the Sinhala herd at Karagoda Uyangoda as based on the total data was found to be 94 gals., which was exclusive of the milk suckled by the calves during milking. The coefficient of variation was 39 per cent. as compared with 20 to 22 per cent. for cattle in temperate countries. The lower lactation yields in the herd were often associated not only with a low average daily yield but also with a short length of lactation, the correlation between total yield and average daily yield being $0{\cdot}82 \pm 0{\cdot}02$ and that between total yield and lactation length $0{\cdot}44 \pm 0{\cdot}04$.

The effect of age at first calving on yield in the first lactation was analysed, and the regression value of 0·13 gals. that was obtained for an increase in age of 1 month was not significant. The variation of yield with age in lactations, though important, was not as large as in European breeds. The results showing this variation as obtained by the 'paired lactation' method are set out in Table 1. For comparison the results obtained by lumping together all the available data according to lactation number are also presented in the same table. The yields of cows that remained in the herd for 2, 3, 4, and 5 lactations respectively are summarized in Table 2.

TABLE 1. *Relation between the Age of the Cow as measured in Lactations and her Lactation Yield*

| | *Yield (gallons)* | | | | |
|---|---|---|---|---|---|
| | *1st Lact.* | *2nd Lact.* | *3rd Lact.* | *4th Lact.* | *5th Lact.* |
| 'Paired lactation' data | 79 | 84 | 84 | 91 | 80 |
| 'Lumped' data . | 78 | 85 | 88 | 103 | 93 |

TABLE 2. *Relation between the Age of the Cow as measured in Lactations and her Lactation Yield*

(Based on cows which have completed 2, 3, 4, and 5 lactations respectively)

| | *Yield (gallons)* | | | | |
|---|---|---|---|---|---|
| | *1st Lact.* | *2nd Lact.* | *3rd Lact.* | *4th Lact.* | *5th Lact.* |
| Cows with complete records for 2 lactations . . | 79 | 84 | .. | .. | .. |
| Cows with complete records for 3 lactations . . | 79 | 87 | 88 | .. | .. |
| Cows with complete records for 4 lactations . . | 84 | 91 | 96 | 105 | .. |
| Cows with complete records for 5 lactations . . | 82 | 95 | 95 | 107 | 93 |

The trend appears to be rather uneven, probably because of the small numbers involved. One fact that emerges fairly clearly is that peak pro-

duction was generally attained by the fourth lactation, which was reached when the cows were about 6½ years old. The rate of increase was such that by the time the cows had completed four lactations, their yields had risen about 15 per cent.

A study of the distribution of calvings in this herd showed that the calvings were fairly evenly distributed throughout the year. Cows calving in June and November gave about 10 per cent. more milk than those calving in other months of the year. There is some suggestion that this may be related to the heavy rains of May and October–November.

The repeatability of milk yield in this herd was studied by considering all cows that have had two or more lactation records. The first lactation appeared to have a lower repeatability than subsequent ones (Table 3). This suggested that culling on first lactation should be restricted to heifers giving very little milk only. An estimate of the average repeatability of milk yield in this herd was obtained by weighting each of the independent estimates presented in Table 3 by the reciprocal of its squared standard error. This method, though not without its disadvantages, does give greater weight to those estimates which were based on the greatest volume of data. It gave an average repeatability of milk yield in this herd of 0·46. This figure is in close agreement with the results reported by various investigators for European cattle.

TABLE 3. *Repeatability of Milk-yield*

| *Lactation number* | *1* | *2* | *3* | *4* |
|---|---|---|---|---|
| 1 | .. | 0·317 | 0·386 | 0·316 |
| 2 | 0·317 | .. | 0·592 | 0·655 |
| 3 | 0·386 | 0·592 | .. | 0·488 |
| 4 | 0·316 | 0·655 | 0·488 | .. |

A reliable estimate of the heritability of milk-yield within the herd could not be arrived at owing to an inadequacy of daughter-dam pairs. The above estimates of repeatability, nevertheless, lend support to the view that heritability would probably be of the order 0·25 to 0·30.

The extent of selection for milk yield in this herd and the probable rate of genetic improvement were calculated on the assumption that heritability was 0·25. It was found that the average genetic superiority of dams of cows as based on the first to fourth lactations was +1·2 gals., whilst the corresponding superiority of dams of bulls was +14·0 gals. The generation intervals were also calculated for the herd with the following results: $L_{CC} = 78$ months, $L_{CB} = 77$ months, $L_{BC} = 65$ months, $L^{BB} = 68$ months, $\Sigma L = 24{\cdot}0$ years, where $L_{CC}$ is the average age of the dams when the heifer calves are born, $L_{CB}$ is the average age of the dams when the bull calves are born, and so on. The total genetic improvement per year was then given by $(15{\cdot}2/24{\cdot}0) = 0{\cdot}6$ gals. Since the average yield per cow in the population studied was 94 gals., a lactation, this means a probable rate of genetic improvement of 0·64 per cent. per year.

*Discussion.*—It would appear from this study of the general life and production statistics of the Sinhala cattle that the probable genetic changes achieved at Karagoda Uyangoda have been meagre. In spite of the greater variation in yield and the relatively greater length of productive herd-life as compared with cattle in European countries, the intensity of culling in this herd has been disappointingly low. If the high average age of cows and bulls at first service is added to this fact, one would have a fairly clear picture of the limitations that have governed the development of this herd.

It may appear therefore that greater attention to these facts and more stringent selection in regard to dams of cows are called for. However, that even under the best conditions of selection the maximum possible rate of genetic gain in a closed herd would seem to be of the order of 1 per cent. of the average yield per year [4]. Obviously, this does not hold out much hope of rapid improvement in a herd with an average lactation yield of under 100 gals. Therefore alternative breeding systems also need to be tried out, such as crossing the local stock with a foreign breed of superior performance, and interbreeding the progeny with a view to evolving a new type.

*Summary.*—A study has been made of the general life and production data of a herd of Sinhala cattle in Ceylon over a period of 14 years. The limitations that have governed the development of this herd have been discussed, and the probable genetic gain in milk-yield from the selection practised has been estimated at 0·6 per cent. of the average yield per year. The conclusion is drawn that there is need for the simultaneous adoption of methods of improvement other than the selection of local stock.

## REFERENCES

1. P. E. P. Deraniyagala, Sinhala Harak, the Indigenous Cattle of Ceylon. Cattle Breeders' Association Illustrated Year-Book, 1939, p. 88.
2. M. Crawford, Some Notes on a Herd of Cattle. The Tropical Agriculturist, 1938, **90**, 348.
3. G. E. Dickerson and L. N. Hazel, The Effectiveness of Selection on Progeny Performance as a Supplement to Earlier Culling in Live Stock. J. Agric. Res., 1944, **69**, 459.
4. J. M. Rendel and A. Robertson, Estimation of Genetic Gain in Milk-Yield by Selection in a Closed Herd of Dairy Cattle. J. Genetics, 1950, **50**, 1.

(*Received November 5, 1952*)

# THE WOOL FINENESS AND PERCENTAGE OF MEDULLATED FIBRES IN WOOL OF LAMBS 1–6 MONTHS OLD

L. KONCAR[1] AND I. SMALCELJ[2]

THE wool of lambs becomes finer, i.e. of less diameter, with increasing age. From the morphological point of view this shows that the phylogenetic manner of forming wool fibre from hair is repeated in embryonic development [1]. Although during the first growth of wool there is a high percentage of medullated fibres, with increasing age the fibres lose the medullar channel and become, on the base of the staple, real wool fibres [2]. According to this, therefore, we can estimate the fineness of the wool, which corresponds with the genetic complex (genom) of wool fineness, at a certain age.

According to proved data, the finest wool in the sheep is grown some time about the age of 3–4 years, and the average fineness about 1–1·5 years [3]. One has often to determine the wool fineness of lambs in the first months of life, and to deduce from this the wool fineness of the individual in the adult stage (e.g. at death, after casualties, on sale, and so on). This is necessary for genetical observations in connexion with the selection of sheep on wool fineness and uniformity. The first determination of the wool is usually made at 6 months. To do this it is necessary to know how the wool fineness of lambs changes during the first 6 months of life. In order to investigate this problem in Bosnian conditions (relatively rough middle-European climate with some Alpine influence; the rainfall high in autumn and spring and low in the summer; mountainous area), we chose 20 $F_1$ lambs (merino rams × 'Pramenka' ewes (native sheep)). Samples of wool were taken at 1, 3, and 6 months from the shoulder, the last rib, and the middle britch. Estimation of wool fineness was made from the base of staple, and the data from the investigated fibres are shown in the accompanying tables.

It is clear from Table 1 that the wool of 1-month-old lambs is finest and most uniform on the shoulder, then on the last rib, and coarsest on the britch. The medullated fibres do not show great differences in fineness in all three regions. Although the average fineness curve of medullated fibres is better in the samples from the britch, standard deviation is larger, and therefore also is the coefficient of variability.

The table shows that there is a high percentage of medullated fibres in the wool of 1-month-old lambs, which is not to be expected in the adult sheep of the same genetical origin.

With 3-months-old lambs, as with those of 1 month, the finest and most uniform wool is on the shoulder, then on the last rib, and finally, although as fine as that on the shoulder, the least uniform wool is on the britch.

[1] Director of Animal Husbandry Institute, Sarajevo, Yugoslavia.
[2] Professor of Veterinary Faculty, Sarajevo, Yugoslavia.

[Empire Journ. of Exper. Agric., Vol. 21, No. 81, 1952.]

TABLE 1. *Fibre Thickness in Wool Samples from Lambs 1 month and 3 months old*

(The figures for 3-months-old lambs are in brackets)

| *Region* | *Number of fibres* | *Mean fibre thickness (microns)* | *Standard deviation (microns)* | *Coefficient of variability (%)* |
|---|---|---|---|---|
| *Shoulder* | | | | |
| Total fibres . . | 10,742<br>(11,199) | 32·13 ± 0·14<br>(30·53 ± 0·13) | 14·40 ± 0·09<br>(13·90 ± 0·09) | 44·82<br>(45·51) |
| Wool fibres . . | 8,443<br>(9,666) | 28·42 ± 0·11<br>(26·60 ± 0·09) | 10·05 ± 0·08<br>(8·85 ± 0·06) | 35·37<br>(33·21) |
| Medullated fibres . | 2,299<br>(1,533) | 52·28 ± 0·24<br>(55·52 ± 0·34) | 11·44 ± 0·17<br>(13·22 ± 0·24) | 21·88<br>(23·39) |
| *Last rib* | | | | |
| Total fibres . . | 10,266<br>(11,220) | 33·02 ± 0·15<br>(32·57 ± 0·16) | 16·09 ± 0·11<br>(17·33 ± 0·11) | 48·73<br>(53·22) |
| Wool fibres . . | 7,782<br>(9,178) | 27·19 ± 0·11<br>(26·05 ± 0·09) | 10·28 ± 0·08<br>(8·38 ± 0·06) | 37·82<br>(32·16) |
| Medullated fibres . | 2,484<br>(2,072) | 52·13 ± 0·23<br>(61·37 ± 0·39) | 11·62 ± 0·16<br>(17·82 ± 0·26) | 21·46<br>(29·04) |
| *Britch* | | | | |
| Total fibres . . | 9,977<br>(11,380) | 33·57 ± 0·15<br>(32·43 ± 0·17) | 14·77 ± 0·10<br>(17·98 ± 0·12) | 44·00<br>(55·45) |
| Wool fibres . . | 7,273<br>(8,797) | 27·21 ± 0·11<br>(26·68 ± 0·09) | 9·99 ± 0·08<br>(8·13 ± 0·06) | 36·70<br>(30·48) |
| Medullated fibres . | 2,704<br>(2,583) | 50·08 ± 0·24<br>(59·48 ± 0·37) | 12.59 ± 0·17<br>(19·12 ± 0·27) | 25·13<br>(32·14) |

There is a significant difference in fineness of wool from lambs at 1 month and 3 months. We have observed that the wool becomes finer with increasing age early after birth. Comparing the wool at 1 and 3 months, it is found that the medullated fibres become thicker with advancing age, and real wool fibres become finer. Such a sequence in wool development is in full accord with the data from histological literature, i.e. with the data on the phylogenesis of wool.

The wool of 6-months-old lambs is finest and most uniform on the shoulder, then the last rib, and coarsest on the britch. The presence of medullated fibres in the wool of investigated samples increased from the shoulder towards the britch. The increased number of medullated fibres affects the average wool fineness from the shoulder towards the britch.

If we compare the wool from the same lambs and the same regions at 1 month and 3 months of age we can conclude as follows:

Whilst with lambs of 1 month and 3 months of age there is an obvious tendency for wool to become finer as the lambs grow, at 6 months there is a tendency for the wool to become coarser. This coarseness is partly due to the medullated fibres of greater diameter (although it is slight owing to the decrease in the number of medullated fibres). It seems that this difference in the fineness of the wool (coarser wool at 6 months, but less medullated fibres) is caused by the transformation of the medul-

TABLE 2. *Fibre Thickness in Wool Samples from Lambs 6 months old*

| *Region* | *Number of fibres* | *Mean fibre thickness (microns)* | *Standard deviation (microns)* | *Coefficient of variability (%)* |
|---|---|---|---|---|
| *Shoulder* | | | | |
| Total fibres | 7,533 | 31·97 ± 0·15 | 13·67 ± 0·11 | 42·77 |
| Wool fibres | 7,307 | 30·67 ± 0·13 | 11·08 ± 0·05 | 36·10 |
| Medullated fibres | 226 | 66·42 ± 1·59 | 23·94 ± 1·16 | 36·04 |
| *Last rib* | | | | |
| Total fibres | 7,504 | 32·65 ± 0·15 | 13·29 ± 0·08 | 40·69 |
| Wool fibres | 7,151 | 30·43 ± 0·13 | 11·19 ± 0·09 | 36·70 |
| Medullated fibres | 353 | 62·01 ± 0·71 | 13·38 ± 0·50 | 21·57 |
| *Britch* | | | | |
| Total fibres | 8,332 | 35·45 ± 0·17 | 15·27 ± 0·12 | 43·07 |
| Wool fibres | 7,782 | 32·85 ± 0·13 | 11·76 ± 0·09 | 35·80 |
| Medullated fibres | 550 | 64·45 ± 0·71 | 16·80 ± 0·53 | 26·07 |

lated substance into the cuticle of the real wool fibre. The results of investigation show that the total amount of wool becomes coarser. Extension of the investigation will throw more light on this problem.

Since the medullated fibres in the wool of the crosses are of primary interest to us because of their lower value for the textile industry, we shall now discuss them.

If we compare the percentage of medullated fibres in the lambs' wool at various ages (Table 3) we can see an obvious regularity in the decreasing percentage of medullated fibres. This percentage is noticed on the shoulder, last rib, and the britch, i.e. in the whole fleece. The decrease of the medullated fibres is striking. For example, the percentage

TABLE 3. *The Percentage of Medullated Fibres in Wool of Lambs 1–6 months old*

| *Region* | *1 month old* | *3 months old* | *6 months old* |
|---|---|---|---|
| *Shoulder* | | | |
| Total fibres | 100·0 | 100·0 | 100·0 |
| Wool fibres | 78·6 | 86·4 | 97·0 |
| Medullated fibres | 21·4 | 13·6 | 3·0 |
| *Last rib* | | | |
| Total fibres | 100·0 | 100·0 | 100·0 |
| Wool fibres | 75·8 | 81·8 | 95·3 |
| Medullated fibres | 24·2 | 18·2 | 4·7 |
| *Britch* | | | |
| Total fibres | 100·0 | 100·0 | 100·0 |
| Wool fibres | 72·9 | 77·3 | 93·2 |
| Medullated fibres | 27·1 | 22·7 | 6·8 |

of medullated fibres on the shoulder decreases from 21·7 in the samples at 1 month, to above 13·6 per cent. at 3 months, to 3 per cent. at 6 months. For the britch these figures are 27·1, 22·7, and 6·8 per cent. respectively.

The decrease in medullated fibres takes place with increasing age. As mentioned before, the first reliable selection of the lambs can take place at the sixth month [4], and at that time the ratio of medullated fibres in the fleece is considerably less than during the first months of life. Such observations are useful from a purely genetical point of view. From this investigation we can see that it would be wrong to compare the wool of adult sheep (parents) with the wool of lambs and to draw conclusions from such a comparison. This work is an attempt to establish the indexes in differences in wool fineness at various ages.

*Summary.*—From the investigation of wool fineness of 20 $F_1$ lambs (merino × 'Pramenka') at 1, 3, and 6 months, on the shoulder, the last rib, and the britch (a total of 51,340 fibres), the following conclusions were drawn:

With increasing age the percentage of medullated fibres decreases and the wool becomes finer, but at 6 months, although the percentage of medullated fibres in the wool decreases regularly, the average thickness of real wool fibres is higher than at 3 months of age. When classifying lambs with regard to wool fineness for genetical purposes it is necessary to keep in mind the change in fibre thickness. This is especially important for the estimation of the medullated fibres in the fleece of crosses between the sheep with coarse fleeces and the merino types where special efforts are made to eliminate the higher percentage of medullated fibres.

## REFERENCES

1. F. ELLENBERGER, Histologie und mikroskopische Anatomie der Haussäugetiere. P. Parey, Berlin, 1905.
2. A. M. LEROY, Le Mouton. Hachette, Paris, 1948.
3. J. L. GLEMBOCKIJ, Plemennoë delo v tankorunem ovtsevodstve, Ogiz-Seljhozgiz, Moskva, 1947.
4. F. KRALLINGER, Angewandte Vererbungslehre für Tierzüchter. E. Ulmer, Stuttgart, 1937.

(*Received July 22, 1952*)

# EXPERIMENTS ON THE MAINTENANCE OF SOIL FERTILITY AT IBADAN, NIGERIA, 1922–51

## PT. 1. *Introduction and Review of the Period 1922–33*

H. VINE

(*Senior Agricultural Chemist, Nigeria*)

*Introduction.*—Investigations of the possibility of maintaining fertility under continuous cultivation in southern Nigerian conditions were begun in 1921. The use of imported fertilizers did not then appear to be economic, and practically no animal manure was available owing to the prevalence of tsetse fly and lack of cattle. It was thought that growing leguminous green manures in rotational cropping might suffice to maintain fertility, for it was considered likely at the outset that the crucial factors in these climatic conditions would be maintenance of the organic-matter content and of the nitrogen supply of the soil.

Encouraging results were obtained from this work at the experiment station at Ibadan (Moor Plantation), where yields were generally maintained at a high level in rotations for as much as 12 years[1] without any fertilizer or manure (other than green manure) being added, the system of continuous cultivation gave the appearance of being a definite improvement on local practice, and the maintenance of yields was taken to be mainly the result of the use of green manures [1, 2, 3].

In contrast, the results of green-manuring at Umuahia Experiment Station [4] and also at Benin, on highly acid soils such as are widespread in SE. Nigeria, were most disappointing; as Faulkner remarked [2], the main leguminous green manures which were tried failed to give satisfactory growth themselves.

Since the last full report on the work at Ibadan was published, in 1938 [3], further experiments have been carried out on some of the land used previously; it has also been found necessary to re-examine the results of the original rotation experiments.[2] The following are now the writer's main conclusions from the field experiments and some related chemical studies:

1. Yields can be maintained at a good level for considerable periods of continuous cultivation on these soils without the use of fertilizers.
2. Fertility is lost rather slowly if continuous cultivation is prolonged for more than about 10 years.
3. In the long run, the nitrate supply is the main controlling factor in Moor Plantation soils, whilst available phosphate is less important as a limiting factor.

[1] During this period, however, yields of yams (*Dioscorea* sp.) were nearly always low at Moor Plantation for some unknown reason other than lack of soil fertility; no satisfactory explanation could be found at the time.

[2] Fuller records of the more recent work and of some of the earlier experiments are being published as a bulletin [5].

[Empire Journ. of Exper. Agric., Vol. 21, No. 82, 1953.]

3988.82 F

4. When land has previously been rather intensively cropped for some years mucuna (the main green-manure crop tried) generally is beneficial to the yield of the crop immediately following it.
5. Incorporation of leguminous green manure results very rapidly in production of nitrate in the soil, and it is this factor that is responsible for the good effect on the following crop.
6. Short-term green manures (such as mucuna) do not produce any lasting increases in the amounts of humus and total nitrogen in the soil, and may not serve to prevent the gradual loss of humus and nitrogen.
7. When the amounts of humus and total nitrogen have become considerably depleted through continuous cropping, short-term green manures do not appear to be capable of maintaining adequate nitrate supplies and high crop-yields in intensive rotations alone.

The earlier conclusion as to the part played by the green manures in the maintenance of yields in the original rotations does not appear to have been justified. On the contrary, as will be shown below, in one of the main experiments (that which compared five rotations having differing frequencies of green manuring) little benefit from the addition of mucuna was evident until the rotations had been in progress for about 10 years. The experiment started on land newly cleared from young secondary forest, and the results strongly suggest that the gradual decomposition of constituents of the humus accumulated in such conditions can provide a nearly adequate supply of nitrate for 10 years or more in these soils.

Faulkner [2] remarked on the difficulty of making a direct estimate of the beneficial effect of a mucuna crop on the crop immediately following; no experiment had been made to compare the yields of a crop grown after a green manure with those after a bare fallow, because it was thought that the difference which would be found would probably represent the loss from allowing the bare plots to be leached by heavy rain, rather than the beneficial effect of the mucuna on the other plots. But Faulkner reckoned the increase in yield of early maize resulting from growing a preceding mucuna crop to be in the order of 600 to 800 lb. of maize per acre. It will be shown below that there were certain experiments that gave evidence of an effect of this order of magnitude, on fields which can be presumed to have been deficient in nitrate supply, whereas in other cases the effect was much smaller. Faulkner appears to have been led to an incorrect interpretation of the action of the mucuna crop (in the experiments comparing different methods for its disposal), by assuming much too high a figure for the total effect of the mucuna on the maize test-crop.

On the other hand, Faulkner's generalization: 'We now regard the after-effect of a green-manure crop (in our conditions), not as something rather similar to that of organic manure in a temperate climate but rather as similar to that of soluble "artificials"', appears to have been well justified, and its correctness is borne out by the later work. Doyne, Hartley, and Watson [6] in fact remarked of mucuna on Moor Plantation

that when incorporated in the soil it behaved very much like a mineral fertilizer such as ammonium sulphate; this point was illustrated by observations on the disappearance of mucuna leaves added to the soil in pots in the laboratory and the resulting formation of nitrate.

Ibadan may be considered to represent a large part of the western Provinces of Nigeria and an even larger area of very similar topography, climate, and soils in the Gold Coast, covered by the 'Dry Forest Zone' and the northern part of the 'Rain Forest Zone' [7]. The mean annual rainfall at Moor Plantation is 48·5 in. (records of 45 years). There are two rainfall maxima, in May–June and September–October; there is a 4-months' dry season having only scattered showers and occasional storms, from mid-November to mid-March, and in most years there is a distinct break in the rains at some time during late July and August. Ibadan is in the middle of the natural zone (80 miles wide) of 'Dry Forest', sometimes described as Semi-deciduous Forest, which separates the Rain Forest Zone of the extreme south of Nigeria from the Savannah Zones of the middle and north of the country. Mature growth of 'high forest' in both Dry Forest and Rain Forest Zones consists of an open top layer of emergents, a fairly open middle layer 50 to 120 ft. high, and a dense understorey of trees and bushes about 15 to 30 ft. high.

Savannah vegetation has encroached from the north over about one-third of the Dry Forest Zone in Western Nigeria, through the action of fires, following on frequent clearing of land for cultivation. The people are active cultivators, and in growing annual crops fairly systematic use is made of the farming land nowadays, with alternate cropping and resting under natural fallow-growth. Shrubs and bushes generally regenerate quickly by coppice-growth after farming, to form a forest thicket or, if given time, secondary forest. But when the land is farmed repeatedly, and if special care is not taken, more and more of the stumps may be killed and grass increases in amount; fires then sweep through repeatedly, and eventually the vegetation changes to savannah. A great deal of the land occupied by 'derived savannah', or in a stage of transition to it, is badly infested with spear grass (*Imperata cylindrica*, Beauv.).

The soils of these parts of Nigeria and the Gold Coast consist (except for small areas in low ground) of loose brownish top-soils over porous reddish to yellowish sand to sandy clay sub-soil layers, of free or very free internal drainage, and situated on gentle to moderate slopes. They vary considerably in their mechanical composition and in their reserves of plant-nutrients, in consequence of differences in parent rocks and mode of accumulation of the soil material (residual or transported). But conditions in the top (humic) layers are affected more by variations in the type of vegetation and the previous history of cultivation and fallow, than they are by the variations in texture and plant-nutrient reserves in the profile.

These soils have characteristics associated with a balance between a moderate degree of leaching, the growth of the vegetation, and the decay, and destruction by worms, termites, ants, &c., of leaves, wood, and roots on and in the soil. A feature which has been particularly stressed [6, 8, 9] is the marked increase of acidity with depth. The top-soil

layers are weakly acid to neutral; rapid decomposition of leaf-litter sets free the ash constituents which have been absorbed from all depths of the soil, and the quantity of bases set free is commonly almost or quite sufficient to saturate the base-exchange capacity of the organic colloids of the surface-layer; there is moderate leaching of bases from this layer, and decreasing amounts of the exchangeable bases leached out are found in successive layers down the profile. In forest conditions the top-soil as a C/N ratio between 10 and 12 (carbon about 1 to 2 per cent., nitrogen about 0·1 to 0·2 per cent.). In savannah country farther north, though the amount of humus is about the same, the C/N ratio is higher and nitrate is deficient in at least the first season on newly cleared land. This difference is clearly demonstrated in the results of Nye's fertilizer experiments in the Gold Coast [10] as well as by experience in Nigeria.

The Moor Plantation experiments are situated on several typical variations of the local soils, derived in this case from medium-grained biotite gneisses. Most of the land had a history of light cropping and bush-fallowing when the experiments started. Soil analyses were not done in the earlier years, except on a few special plots. Figures obtained during the last 15 years for the pH of the top-soil are about 5·8 to 6·5, for carbon-content about 0·4 to 0·8 per cent., and for nitrogen about 0·3 to 0·6 per cent. In general, the amount of organic matter is inversely related to the coarseness of texture, but it has decreased appreciably during the course of the more intensive rotations [5]. Fertilizer experiments showing that deficiency of nitrate has generally become very marked after long periods of cultivation, whilst phosphate deficiency is less marked, will be mentioned in Part 2. These results are in contrast to those of the recent fertilizer experiments on similar soil types in the Gold Coast [10, 11]; in these the sites were all relatively newly cleared from forest growth, and the absence of any appreciable deficiency of nitrate accords with the writer's explanation of the maintenance of yields in the earlier years at Moor Plantation, given above; on the other hand, the frequent occurrence of quite large responses to superphosphate on these sites in the Gold Coast suggests that Moor Plantation may be somewhat exceptional in its general level of phosphate supply.[1]

The problems of crop growth and maintenance of fertility are very different in the southern part of the Eastern Provinces of Nigeria, where the annual rainfall is 90 to 150 in. or more and the soils are intensely leached and acid, from those of the Ibadan area.

Table 1 gives a summary of various rotations mentioned in this paper.

### *Work of the Period 1922–33*

A straightforward trial of the practice of green manuring was begun in 1922–3 with a single 4-year rotation (the '1922–33 Main Rotation') on

[1] This has been pointed out privately by Mr. P. H. Nye, who suggests the possibility that the biotite gneisses occurring at Moor Plantation may give rise to a better phosphate supply than do many of the other rocks of the Basement Complex (particularly some schists and granites), and also that disturbance of the soil through former settlement, chance distribution of domestic refuse, &c., may be more extensive on the main experimental fields here than is at first apparent.

eight fields of 5 acres each, which covered noticeable variations in soil. There are two growing-seasons each year at Ibadan, and it was found satisfactory to grow a short-term green manure in either the early or the late season, with maize, yams, cotton, or groundnuts in the other part of the year; cassava and minor crops were omitted from the rotation trials until a later date.

TABLE 1. *Summary of Various Rotations*

| *Rotation* | *1st year* | *2nd year* | *3rd year* | *4th year* |
|---|---|---|---|---|
| 1922–33 Main Rotation . . | E. maize<br>Mucuna | Yams<br>Mucuna | Mucuna<br>Cotton | Groundnuts<br>Mucuna |
| Rotation I. YA–D. 1923–30/39 . | Mucuna<br>Cotton | Mucuna<br>L. maize | Groundnuts<br>Mucuna | Yams<br>Mucuna |
| Rotation II. ,, ,, | Mucuna<br>Cotton | E. maize<br>Mucuna | Groundnuts<br>Mucuna | Yams<br>Mucuna |
| Rotation III. ,, ,, | Mucuna<br>Cotton | Groundnuts<br>Mucuna | E. maize<br>L. maize | Yams<br>Mucuna |
| Rotation IV. ,, ,, | Groundnuts<br>Cotton | E. maize<br>L. maize | Groundnuts<br>Mucuna | Yams<br>Mucuna |
| Rotation V. ,, ,, | Groundnuts<br>Cotton | E. maize<br>Cowpeas | E. maize<br>L. maize | Yams<br>Mucuna |
| 1934–45 Main Rotation . . | E. maize | Yams | E. maize | E. maize / Mucuna |
| | Popondo | Popondo | Cotton | L. maize / Popondo |
| 1938–45 Rotation 'A' . . | Yams | E. maize | E. maize / Mucuna | E. maize |
| | Mucuna | Cotton | L. maize / Mucuna | Mucuna |
| 1938–45 Rotation 'B' . . | Yams | Groundnuts | E. maize | Cassava / Mucuna |
| | Mucuna | L. maize / Mucuna | Cassava / Cowpeas | Tobacco |
| 1938–45 Rotation 'C' . . | Yams / E. maize | E. maize / Melons | Yams / Okra | Groundnuts |
| | Mucuna | L. maize / Mucuna | Mucuna | L. maize / Mucuna |
| 1938–45 Rotation 'D' . . | Yams<br>Cotton / Cowpeas | E. maize<br>Mucuna | Yams<br>Cassava / Cowpeas | Cassava<br>Mucuna |
| 1946–51 Rotation 'P' . . | E. maize<br>Cotton / Cowpeas | Mucuna<br>L. maize | Yams<br>Cassava / Cowpeas | Cassava<br>Mucuna |

*Mucuna deeringiana* (Bort) Holland (syn. *Mucuna utilis* Hort.; syn. *Stizolobium deeringianum* Bort), known elsewhere as Bengal Bean or Velvet Bean, was adopted for general use as the green-manure crop, being easily grown and rapidly forming a dense cover. On the whole it gave somewhat higher yields in a succeeding maize crop than other species used in comparative trials. It is noteworthy that, of these trials, the one which gave the clearest evidence that green manures actually had a manurial effect started on land which had previously been exhaustively

cropped for 8 years. In this trial mucuna, 'popondo bean', 'lima bean', and a non-leguminous plant forming a dense leafy cover, *Quamoclit coccinea* Moench., were grown and dug in in preparation for early maize, giving, respectively, the following average yields of maize over 8 years (using a 4×4 Latin Square layout): 1,350, 1,160, 1,130, and 780 lb. dry grain per acre; soil-nitrate determinations, which were done on two occasions, showed a correlation between nitrate supply and maize yield.

The 1922–33 Main Rotation showed no appreciable decline in yields during the 12 years that it was in progress, this being made the more striking by the fact that there was a continuous succession of very good seasons for early maize from 1922 to 1932. The cropping scheme was as follows:

*1st year*. Maize sown in April; mucuna interplanted in June, maize harvested in August, and mucuna ridged into the soil in October or November; yams planted in November.

*2nd year*. Mucuna planted through the yams in July, and yams harvested in October or November.

*3rd year*. Existing mucuna continued (more seed planted if necessary) and dug into the soil in June; cotton planted early in July.

*4th year*. Cotton harvested in January, groundnuts planted in March and harvested in August, and mucuna sown in August for digging in the following March.

Local farmers were favourably impressed [1] by the yields obtained in this rotation, but it was not surprising to find them unwilling to grow mucuna crops, in which they could see no intrinsic value. A main objection was to the hard work of digging bulky green material into the soil three times in 4 years, for in local practice the soil is thoroughly cultivated only once in a cropping cycle, when it is made up into heaps for the yam crop, and later cultivations consist only of scraping up weeds and some soil on to the old heaps.

Positive evidence on the action of mucuna crops was given by a well-replicated comparison between the two rotations summarized in Table 2.

TABLE 2. *Cropping and Yields in the 1927–30 Green-Manuring Experiment*

Maize as dry grain, cotton as seed cotton, yams as net yield (gross yield minus weight planted)

| | (1) *10 odd-numbered plots* | (2) *9 even-numbered plots* |
|---|---|---|
| 1927 | Mucuna and cotton | Mucuna and cotton |
| 1928 | Mucuna<br>Late maize 1,139 lb./acre | Early maize 1,290 lb./acre<br>Late maize 594 lb./acre |
| 1929 | Early maize 1,094 lb./acre<br>Mucuna | Mucuna<br>Mucuna |
| 1930 | Yams 10,900 lb./acre<br>Cotton 389 lb./acre | Yams 9,950 lb./acre<br>Cotton 337 lb./acre. |

Faulkner discussed this experiment [2] and pointed out that the early maize crops in 1928 in Rotation (2) and in 1929 in Rotation (1) gave yields 630 and 836 lb. per acre respectively below the average yields obtained after mucuna on Moor Plantation in those years; and similarly the late maize yield in 1928 was 545 lb. per acre less in Rotation (2) (following an early maize crop) than in Rotation (1) (following mucuna). The indications were therefore that mucuna had a large beneficial effect on the next succeeding crop; but the experiment also indicated that this effect was then largely exhausted, because early mucuna in 1927 in Rotation (2) had little effect on early and late maize in 1928, after the intervening cotton crop, and early mucuna in 1928 in Rotation (1) had little effect on early maize in 1929, after the intervening late maize.

A comparison between five 4-course rotations (summarized together with other rotations in Table 1) was begun in 1923 on a 20-acre block of newly cleared land, divided into four sections (YA, YB, YC, YD), and starting with Course 1 of the rotations on YA, Course 2 on YD, Course 3 on YC, and Course 4 on YB. Each section was divided into ten plots, two of which were used for each rotation. The experiment continued for 8 years on YA, 9 years on YD, 11 years on YB, and 18 years on YC.

Yields were fully maintained for 8 to 11 years in all the rotations. Figures for the four sections of the field have been combined in Table 3,

TABLE 3. *Average Yields of Four-course Rotations on Fields YA, YB, YC, and YD Combined*

*R* denotes crops grown on newly made ridges
*M* denotes crops grown on old ridges, moulded up

| | *1st course* | *2nd course* | *3rd course* | *4th course* |
|---|---|---|---|---|
| Rotation I | Mucuna | Mucuna | Groundnuts (*M*) 1,011 | Yams (*R*) 3,660 |
| | Cotton (*R*) 449 | Late maize (*R*) 1,431 | Mucuna | Mucuna |
| Rotation II | Mucuna | Early maize (*M*) 1,958 | Groundnuts (*R*) 937 | Yams (*R*) 3,890 |
| | Cotton (*R*) 463 | Mucuna | Mucuna | Mucuna |
| Rotation III | Mucuna | Groundnuts (*M*) 880 | Early maize (*R*) 2,118 | Yams (*M*) 2,680 |
| | Cotton (*R*) 476 | Mucuna | Late maize (*M*) 1,294 | Mucuna |
| Rotation IV | Groundnuts (*R*) 1,059 | Early maize (*M*) 1,786 | Groundnuts (*M*) 936 | Yams (*R*) 3,720 |
| | Cotton (*M*) 364 | Late maize (*M*) 1,092 | Mucuna | Mucuna |
| Rotation V | Groundnuts (*R*) 1,108 | Early maize (*M*) 1,898 | Early maize (*R*) 2,130 | Yams (*M*) 3,100 |
| | Cotton (*M*) 374 | Cowpeas | Late maize (*M*) 1,050 | Mucuna |

*Note.* Yields expressed in lb. per acre: yams as net yield (gross yield minus weight of planting material); maize as dry grain; groundnuts as dry unshelled nuts (nuts plus shells); cotton as seed cotton.

to show the average yields (from eight plots) of the various crops in each rotation (omitting some results for years when the normal routine or variety was not adhered to).

In Rotations I, II, and IV the average net yields of yams, following mucuna, were 3,660, 3,890, and 3,720 lb. per acre respectively; in Rotations III and V, following early and late maize crops, the yields were reduced to 2,680 and 3,100 lb. respectively. Much, if not all, of the reduction in yield is attributable, not to any beneficial effect of mucuna as compared with maize, but to two complications resulting from the fact that the yams were planted in November: (*a*) the land could not be properly re-ridged in Rotations III and V, on account of there still being the late maize crop on the field, and (*b*) the normal application of grass mulch to promote early sprouting of the yams was delayed until January in these two rotations. Experimental results and general experience have shown that a reduction of 1,000 lb. per acre in yield could very well have been caused by these two factors.

Cotton followed mucuna in Rotations I, II, and III, giving an average yield of about 460 lb. per acre in each case, compared with about 370 lb. per acre in Rotations IV and V, where it followed groundnuts. Here the reduction in yield is attributable to the complications in the planting of cotton early in July. In Rotations I, II, and III the mucuna was ridged in at this time, but in the other two rotations the cotton was planted through the groundnut crop, with the result that its growth was at first liable to be hindered by the groundnuts, and also that harvesting of these in August (sometimes in September) was liable to disturb the young cotton plants, however much care was taken to avoid doing this.

The average yields of early maize obtained after ridging in mucuna in Rotation III, and cowpeas (sometimes replaced by mucuna) in Rotation V, were 2,118 and 2,130 lb. per acre. In Rotations II, III, and V an early maize crop was planted on old ridges which were only moulded up after cotton, and average yields were 1,958, 1,786, and 1,898 lb. per acre respectively. Taking the means of these figures, the reduction in yields was 243 lb. per acre. Similarly, in the case of late maize there was an average reduction in yields of 286 lb. per acre when the crop was planted on old ridges after early maize (in Rotations III, IV, and V) instead of on new ridges after digging in mucuna (in Rotation I). It is known that thorough preparatory cultivation does have a small, though unprofitable, effect on a maize crop at Moor Plantation, and this was most probably partly responsible for the greater yields after digging in mucuna.

The average yields for the first 8 to 9 years of the experiment thus show very little beneficial effect of green manuring. Since it is known that mucuna dug into the soil provides a ready source of additional nitrate it seems evident that there was no lack of nitrate in the soil during this period, even when crops were not immediately preceded by green manure.

The same rotations were continued until 1940 on Field YC. Here, after 12 years, the yields of early and late maize declined markedly in Rotation V (the most intensive of the rotations), and that of late maize

also declined in Rotation III, where the crop was not immediately preceded by green manure. There was a similar result on Field YA and on three other fields which had a previous history of continuous rotational cropping, where some new rotations were begun in 1931 and continued until 1938. On these fields the average yield of early maize crops after digging in green manure was 1,833 lb. per acre, and after scraping up old ridges, following late maize or cotton, it was 1,284 lb. per acre, a difference of 549 lb. per acre. (Details are given elsewhere [5].) These later results show that mucuna was evidently having a marked manuring effect, for which an increased nitrate supply can be assumed to have been responsible. The contrast to the earlier years of cropping strongly suggests that the level of supply of nitrate through decomposition of accumulated humus had decreased considerably.

*Experiments on methods of disposal of the mucuna crop.*—The farmers' objections to the hard work of digging mucuna into the soil when it was bulky and green were considered to form a serious drawback. It was apparent that the work would be much reduced if the material could first be allowed to dry, either by maturing and dying back or by being cut and left on the surface for some time. Trials were begun in 1926 to see if these treatments of mucuna led to any loss of effect. At the same time it was considered desirable to ascertain whether any important part in the (supposedly large and general) beneficial effect of burying mucuna was attributable to the actual digging of the soil, and a comparison was made between re-ridging the land, on 'control' plots, and scraping up soil on to old ridges, on 'treatment' plots; to facilitate this experiment the mucuna crop on all plots was not only cut and dried, but was burnt after drying. In these experiments there was continuous cropping with early maize, interplanted with mucuna in June, each year; the mucuna formed a good bulky cover after harvesting of maize in August.

The surprising result was that yields of maize were only reduced by a small amount if the mucuna were dug in dry or *even if it were burnt and the ashes dug in*, as compared with yields after digging the crop in green. There was also only a small loss of yield from moulding-up old ridges, compared with re-ridging.

Three new experiments to give information on the relative effects of digging-in and burning the mucuna, in continuous cropping with early maize and late mucuna each year, were started in 1931, as described by Faulkner [2], some additional treatments being included, thus:

Field B7–8. Ridged in November–December: 9 plots, mucuna dug in green; 8 plots, mucuna burnt and ashes dug in.

Field A5S. Ridged in November–December: 10 plots, mucuna dug in green; 5 plots, mucuna burnt and ashes dug in; 4 plots, mucuna completely uprooted and carried off.

Field C3W. Ridged in February: 10 plots, mature mucuna dug in; 3 plots, mucuna cut green in November, left on surface until February, then dug in; 3 plots, mature mucuna burnt and ashes dug in; 3 plots, mature mucuna cut and carried off.

Writing in 1934 Faulkner [2] discussed the yields of the first two

test-crops of early maize in these experiments.[1] Slightly higher yields were obtained on the 'burnt' plots than on the 'dug-in'; whilst on A5S and C3W there was a distinct decrease of yield resulting from carrying off the mucuna (either uprooted or cut), amounting to 110 to 190 lb. of dry grain per acre (16 to 30 per cent. of the yields of the 'dug-in' plots, which gave poor yields themselves, especially in 1933). Faulkner suggested that continuing to burn the mucuna year after year must be expected to lead eventually to a gradual decline of fertility, but remarked that the results to date (for the 8 years 1926–33) for the original experiment in which mucuna was burnt showed that such a cumulative decline, if it were occurring at all, was very slow.

From the fact that burning resulted in no loss of yield Faulkner concluded that the addition to the soil of the bulk organic matter and nitrogen in the above-ground part of the mucuna did not have an important manuring effect. He considered the accumulation of the ash constituents in the leaves and stems to become readily available to the succeeding crop (whether after 'burning' or after 'digging-in-green'), to be one important factor.[2] But as complete removal of the mucuna apparently caused a loss in maize yield considerably less than the figure of 600 to 800 lb. per acre, which was assumed to be the net increase given by a mucuna crop preceding maize, it appeared that there must be another factor, of greater importance. Faulkner considered that this was an increased supply of available nitrogen, and one suggestion to account for this was that there was a stimulating effect in the soil during the growth of mucuna; an alternative suggestion was that the increased supply of available nitrogen might have been due to the decomposition of the roots and nodules left in the soil when the above-ground part of the plant was burnt (or even to the decomposition of such residue of roots and nodules as were left in the soil when complete uprooting and removal were attempted).

The hypothesis that mucuna had a stimulating effect, during its growth, on organisms affecting the nitrogen supply of the soil, influenced the design of new rotations, discussed below, in which modified use of green manure was made. Study of a paper by Lewin [1] shows that this idea, which Faulkner thought might explain the experimental results, arose in the first place from periodic determinations of total nitrogen in surface-soil samples made by Diamond between 1926 and 1929 [14]. Diamond reported considerable fluctuations in total-nitrogen content to occur, not only from week to week but even during the course of a day; there were reported to be increases and subsequent decreases of as much as 0·0133 per cent. nitrogen in the top-soil (approximately 500 lb. of nitrogen per acre) within a few days. From these results it was supposed that fixation of atmospheric nitrogen could occur at an extraordinary rate during the growth of mucuna on these soils, and that this factor could be more important than the addition of nitrogen by digging in the

[1] The later results of these experiments are mentioned below; the relative yields of the various treatments did not change much from those found in the first 2 years.

[2] This was more strongly stressed later by Doyne [13].

leaves and stems of a mucuna crop. Determinations of total nitrogen were carried out on samples taken at fortnightly intervals in 1947 in one of the green-manuring experiments (Field B7–8), using composites of about 50 acres to eliminate sampling errors, and these showed no rapid changes (see Table 8 below). There can be little doubt that the apparent fluctuations reported by Diamond were due only to sampling errors.

### Pt. 2. *Later Rotation and Manuring Experiments*

In 1934 a new rotation was substituted for the 1922–33 Main Rotation, in which yields had been successfully maintained but which, it was considered, local farmers could never be persuaded to adopt. The following radical changes were made:

(*a*) Cropping was made more intensive, by increasing the number of maize crops in 4 years from one to four, whilst leaving out the crop of groundnuts formerly grown.
(*b*) The local edible bean 'popondo' (variety of *Phaseolus lunatus* Linn.), which the latest experiments had shown to be possibly equal to mucuna as a green-manure crop, was substituted for mucuna in the second part of the year.
(*c*) In one course of the rotation mucuna was grown in a mixture with early maize, followed by late maize mixed with popondo (presumably on the assumption that these interplanted legumes would still have the supposed important 'stimulating effect' on the soil nitrogen supply).
(*d*) Burning of the 'green manures' was introduced.

The details of the new rotation (the '1934–45 Main Rotation') were as follows:

*1st year*. Early maize, followed by popondo (dug in).
*2nd year*. Yams, followed by popondo (burnt; ashes scraped up on old ridges).
*3rd year*. Early maize, followed by cotton.
*4th year*. Early maize, mixed with mucuna (dug in), followed by late maize, mixed with popondo (burnt; ashes scraped up on old ridges).

On account of seasonal effects, Army Worm and locust attacks, and other misfortunes, it was not immediately apparent whether the new rotation was maintaining fertility as well as the old one had done.

In 1938 the main rotation was reduced to four of the eight 5-acre blocks, whilst the other four were laid out in an experiment involving four rotations, of which 'Rotation A' was the same as the 1934–45 Main Rotation, except that popondo was discarded and mucuna again used in its place, whilst 'B', 'C', and 'D' were thought to be more suitable for adoption locally, as they included a greater variety of crops and a smaller proportion of maize than did the 1934–45 Main Rotation (see p. 69).

By 1944 it was apparent that poor yields were being obtained consistently in the Main Rotation and Rotations A, B, and C, although good

growth and fairly good yields of yams and maize were generally to be observed in Rotation D. Some of the maize crops showed typical signs of nitrate deficiency.

A remarkable result had been obtained in a pot experiment carried out in 1943, using the top-soil from a small plot (having a deep sandy profile and situated on the hill-top) which had been kept clean-weeded for several years and had lost a large proportion of its organic matter. The experiment included applications of sulphate of ammonia, superphosphate, and potash, singly and in combinations; lime and minor elements were added in some treatments. Hill rice was used as the test crop. Sulphate of ammonia alone produced very good growth and yields, but there was no response to phosphate, potash, lime, or minor elements. The writer had suggested that an important feature of the Moor Plantation soils was the presence of incompletely weathered minerals, especially biotite, in the soil (or in decomposing rock within reach of plant-roots), which provided reserves of fertility. It was therefore of interest to obtain an indication from the pot experiment that the loss of fertility caused by clean-weeding (with exposure to leaching) was essentially a matter of depletion of available nitrogen, not of the ash-constituents.

In 1944, therefore, a factorial experiment with N, P, and K was carried out on the early maize crop on small plots situated in two of the main fields (in Rotation A in one case and Rotation D in the other). The yields and 'main effects' obtained are shown in Table 4. There was a great response to sulphate of ammonia (at 2 cwt. per acre), but none to phosphate (basic slag at 4 cwt. per acre) or to potash (sulphate of potash at 1 cwt. per acre). It is possible that superphosphate would have had some effect if it had been available in place of basic slag, but obviously the main deficiency was that of nitrogen.[1]

TABLE 4. *1944 Fertilizer Experiment*

Early maize yields in lb. of dry grain per acre

| | *Rotation A Field Z5S* | | *Rotation D Field B4W* | | *Two fields combined* | |
|---|---|---|---|---|---|---|
| *Nitrogen effect* | *With* N | *No* N | *With* N | *No* N | *With* N | *No* N |
| Av. yield (lb./acre) | 1,166 | 557 | 1,705 | 1,328 | 1,435 | 942 |
| Increase | 609 | | 377 | | 493 | |
| Increase (per cent.) | 109·3 | | 28·4 | | 52·4 | |
| *Phosphate effect* | *With* P | *No* P | *With* P | *No* P | *With* P | *No* P |
| Av. yield (lb./acre) | 895 | 828 | 1,490 | 1,543 | 1,192 | 1,185 |
| Increase | 67 | | −53 | | 7 | |
| Increase (per cent.) | 8·1 | | −3·4 | | 0·6 | |
| *Potash effect* | *With* K | *No* K | *With* K | *No* K | *With* K | *No* K |
| Av. yield (lb./acre) | 872 | 851 | 1,574 | 1,459 | 1,222 | 1,115 |
| Increase | 21 | | 115 | | 67 | |
| Increase (per cent.) | 2·5 | | 7·9 | | 5·8 | |

[1] In 1937 factorial experiments with fertilizers were begun at Moor Plantation and three other stations in southern Nigeria, which were intended to continue indefinitely

Further confirmation of the general shortage of nitrate was given by the very striking results of an experiment with sulphate of ammonia on cotton in the 1934–45 Main Rotation, in 1945. Additional evidence that lack of nitrogen was the main and possibly the only important nutritional factor was given by the fact that yields of groundnuts (a leguminous crop) in Rotations B and C had remained at the same high level as in the original 1922–33 Main Rotation—about 1,250 lb. of dry nuts (kernels plus shells) per acre.

It was concluded that the decline in yields and general deficiency of available nitrogen were due to there being insufficient well-grown green manure added to the soil, except perhaps in Rotation D. The main defect of this rotation appeared to be that the growing of yams twice in 4 years led to very high incidence of eel-worm disease of the tubers. New rotations, based on Rotation D but with maize or other crops substituted for one of the yam crops, were begun on the old fields in 1946.

The crop yields obtained in these new rotations (started in 1946) have actually been similar to those which were given by Rotation D, except that there have been disasters of Army Worm and Rust (*Puccinia polysora* Underw. [12]) attack on maize in 1950 and 1951, and very low percentage establishment of yams in 1946 and 1950, due to unsatisfactory planting material. Only one of these rotations, Rotation P, need be considered here; the details are as follows:

*1st year.* Early maize planted in April after ridging in previous mucuna; cotton (replaced by okra after 1947 on account of the repeated ruination of cotton crops by Boll-Worm and *Helopeltis* attacks) interplanted in July, and cowpeas (*Vigna unguiculata* (Linn.) Walp.) interplanted in September.

*2nd year.* Mucuna planted on moulded-up ridges in March–April, and ridged in in August; late maize planted in September.

*3rd year.* Maize residues ridged in and yams planted in February; cassava interplanted in June–July, and cowpeas interplanted in September.

*4th year.* Cassava continued and harvested in August; ridges moulded up and mucuna planted in September.

Rotation P has been used for a fertilizer experiment comparing the six treatments: *o*, *p*, *pk*, *n*, *np*, *npk*. The fertilizers have been applied twice in the rotation—to the yams in Course 3 and to the maize in Course 1 (except that in 1947 only the phosphate and potash were

but had to stop in 1940 owing to lack of supplies of fertilizers. The experiment at Moor Plantation (cropped with maize and mucuna) was on land which had been under a good fallow cover for 2 years, and yields were very high; in 1938, 1939, and 1940 phosphate (superphosphate at 3 cwt. per acre) gave an average increase of about 200 lb. of dry grain per acre (with an average of 2,030 lb. per acre on no-phosphate plots), whilst nitrogen and potash were without effect.

An earlier factorial experiment, in which only one test crop was grown, and which was also on land that had been out of cultivation for 2 years previously, showed an increase of 250 lb. per acre of late maize resulting from 1 cwt. of sulphate of ammonia per acre (compared with 1,500 lb. per acre on no-nitrogen plots), whereas superphosphate and muriate of potash had no effect.

applied to the maize, and the nitrogen was applied to the cotton crop) Rates of application were: *n* sulphate of ammonia at 3 cwt. per acre; *p* superphosphate at 2 cwt. per acre; *k* muriate of potash at 1 cwt. per acre. Potash has had no appreciable effect on yields, and is evidently not liable to become deficient in these soils. The effects of nitrogen and phosphate on yams and maize are shown in Table 5. The figures show large responses to sulphate of ammonia on every occasion, and some response of maize to superphosphate.

TABLE 5. *Fertilizer Experiment on Rotation P*

Early maize yields in lb. of dry grain per acre.
Yam yields in lb. per acre net (gross yields minus weight of planting material).
(*Notes.* (1) In 1950 and 1951 maize yields were reduced to about 200 lb. per acre by severe attacks of Rust.
(2) In 1949 there was only 28 per cent. establishment of yams, due to unsatisfactory planting material.)

| | *o* | *n* | *p* | *np* | N *effect* | P *effect* | N×P *interaction* |
|---|---|---|---|---|---|---|---|
| (1) *Early maize* | | | | | | | |
| 1946 Field D5N | 1,375 | 1,987 | 1,571 | 2,423 | 732‡ | 316‡ | +240* |
| 1947 ,, B4W | 1,696 | .. | 1,704 | .. | .. | 8 | .. |
| 1948 ,, Z7N | 1,724 | 2,668 | 1,955 | 2,923 | 956‡ | 243‡ | +24 |
| 1949 ,, Z5S | 1,854 | 2,672 | 2,069 | 2,857 | 799* | 196* | −36 |
| (2) *Yams* | | | | | | | |
| 1947 Field Z5S | 9,296 | 15,810 | 8,544 | 16,560 | 7,265‡ | −1 | +751 |
| 1948 ,, D5N | 6,504 | 8,432 | 6,276 | 10,180 | 2,691* | 985 | +763 |
| 1949 ,, B4W | −32 | 1,270 | −118 | 460 | 940 | −448 | −362 |
| 1950 ,, Z7N | 5,414 | 9,298 | 6,306 | 7,582 | 2,580‡ | −412 | −1,304† |
| 1951 ,, Z5S | 9,650 | 16,181 | 9,676 | 14,505 | 5,680* | −825 | −851 |

* Significant at 20:1 level. † Significant at 10:1 level.
‡ Significant at 100:1 level.

Detailed consideration of the yield records for the various rotations since 1934 (reported elsewhere [5]) bears out the conclusion that there has been a general deficiency of nitrate in the soil, more or less severe on different fields, and that well-grown mucuna crops have had a markedly beneficial effect in supplying nitrogen to the non-leguminous crops immediately following them. Thus, the average yields of Rotations A and D from 1938 to 1945 are summarized in Table 6, and in these the following points are noteworthy:

(*a*) The yam crops were preceded by sole crops of mucuna (dug in) and gave very similar average yields, in Course 1 of Rotation A and Courses 1 and 3 of Rotation D; these yields were fairly good.
(*b*) Cotton was a failure in both rotations, and this was largely attributable to nitrate deficiency; in neither case was it preceded by green manure.
(*c*) Early maize in Course 2 gave a fairly good average yield in both rotations; in A it was preceded by mucuna (burnt), and in D by cowpeas (planted through the unsuccessful cotton).

(*d*) The maize crops in Courses 3 and 4 of Rotation A gave very poor yields, and the interplanted mucuna crops in Course 3 proved to be of no benefit to the succeeding crops unless they were planted so early as to interfere seriously with the growing maize.

(*e*) Cassava in Rotation D gave only about half the yield obtainable on good land; the varieties which were grown (maturing in about 14 months) yielded over 20,000 lb. per acre in the same years in an experiment on more fertile soil.

TABLE 6. *Average Yields (1938–45) from Rotations A and D in lb. per acre*

(*Note.* Yam yields for 1944 have been omitted in calculating the averages, because the crop in rotation A was smothered by mucuna, planted much too early by mistake.)

| | *Course 1* | *Course 2* | *Course 3* | *Course 4* |
|---|---|---|---|---|
| Rotation A | Yams 6,210 | E. maize 1,540<br>Cotton 40 | E. maize 850<br>L. maize 400 | E. maize 870 |
| Rotation D | Yams 7,490<br>Cotton 25 | E. maize 1,540 | Yams 6,500 | Cassava 11,620 |

Rotations B and C need not be considered here, except for observing that in B mucuna was only grown once as a sole crop and this preceded groundnuts, so that the beneficial effect which it might have had was wasted, whilst Rotation C had a wasted crop of mucuna in Course 3, preceding groundnuts, one other sole mucuna crop, and mucuna interplanted with late maize twice.

In the later rotations, started in 1946, there have been frequent instances of poor growth, pale yellowish leaves, and low yields, all attributable to serious nitrogen deficiency, particularly on maize and cassava crops. Four of these rotations (including Rotation P) have included two crops of mucuna (dug in) and two crops of cowpeas, whilst the fifth rotation has included one crop of groundnuts, two crops of cowpeas, and only one of mucuna. Though cowpeas appear to have had some beneficial effect, in addition to that of mucuna, these proportions of leguminous green-manure crops are evidently not sufficient to supply the amounts of nitrate required for good yields, when the humus-content of the soil has been seriously depleted by prolonged cultivation.

### *Burning of Green-manure Crops: Effects on Maize Yields and Nitrate-content of Soil*

The experiments started in 1931 mentioned above (p. 73) comparing the burning of mucuna with digging it into the soil, were continued for 20 years (on B7–8), 9 years (on A5S), and 7 years (on C3W), and during these periods they showed no marked adverse effect of the burning on the yields of the early maize test crops (which are shown in Table 7). This result appears to conflict with all the evidence given in the last section that maintenance of the available nitrogen supply is the most important factor in these soils.

TABLE 7. *Treatment of Mucuna Experiments*

Yields of early maize in lb. per acre

| | *B7–8* | | *A5S* | | | *C3W* | | | |
|---|---|---|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| 1932 | 1,644 | +7 | 946 | −4 | −169* | 1,163 | +148 | +227 | −191 |
| 1933 | 777 | −82* | 375 | +55 | −112* | 717 | −9 | +131 | −144 |
| 1934 | 1,084 | +18 | 1,142 | +8 | −395* | 1,091 | −96 | +21 | −291* |
| 1935 | 1,726 | +27 | (destroyed by locusts) | | | | | | |
| 1936 | 680 | −49 | (destroyed by Army Worm) | | | 311 | −107 | −56 | −91 |
| 1937 | 1,586 | −117* | 958 | +74 | −283* | 1,294 | +29 | −15 | −322* |
| 1938 | 1,953 | −92 | 857 | +120 | −384* | 1,277 | +47 | −39 | −355* |
| 1939 | 1,811 | +202* | 839 | −22 | −439* | .. | .. | .. | .. |
| 1940 | 1,144 | −89 | 699 | +30 | −308* | .. | .. | .. | .. |
| 1941 | 1,239 | −93* | .. | .. | .. | .. | .. | .. | .. |
| 1942 | 1,638 | −95 | .. | .. | .. | .. | .. | .. | .. |
| 1943 | 1,424 | +152* | .. | .. | .. | .. | .. | .. | .. |
| 1944 | 758 | +257* | .. | .. | .. | .. | .. | .. | .. |
| 1945 | 1,863 | −8 | .. | .. | .. | .. | .. | .. | .. |
| 1946 | 1,330 | −20 | .. | .. | .. | .. | .. | .. | .. |
| 1947 | 1,093 | +291* | .. | .. | .. | .. | .. | .. | .. |
| 1948 | 1,832 | −4 | .. | .. | .. | .. | .. | .. | .. |
| 1949 | 1,582 | −11 | .. | .. | .. | .. | .. | .. | .. |
| 1950 | 452 | −216* | .. | .. | .. | .. | .. | .. | .. |
| 1951 | 390 | −50 | .. | .. | .. | .. | .. | .. | .. |
| Average | 1,300 | +1 | 831 | +37 | −299 | 976 | +2 | +45 | −232 |

*Notes.* (*a*) Columns (2) and (3). Yields from mucuna dug in green, Nov.–Dec.
Columns (1) and (4). Yields from mucuna burnt, ashes dug in, Nov.–Dec.
Column (5). Mucuna pulled and carried off (1931 to about 1936); cut and carried off (about 1936 to 1939).
Column (6). Yields from mucuna cut and dug in in February.
Column (7). Yields from mucuna cut in November, dug in in February.
Column (8). Yields from mucuna cut and burnt in February, ashes dug in.
Column (9). Yields from mucuna cut and carried off in February.
(*b*) Maize crops on B7–8 in 1950 and 1951 ruined by Army Worm and Rust attack.
(*c*) * indicates significant difference.

It appears that in the conditions of these experiments there is a rough balance between two opposing factors which are involved in the two treatments—increased availability of phosphate in the earliest stages of growth of the maize, after burning, and decreased supply of nitrate. In the first few weeks of growth the maize on the 'burnt' plots has always been noticeably ahead of that on the others, and it is thought that this can be attributed to the fact of the phosphate contained in the mucuna being made very readily available by burning, for it is known that cereal crops benefit especially from phosphatic manure in the earliest stages of growth. Usually the 'dug-in' plots have been observed to catch up with the 'burnt' plots, remain green longer, and, sometimes, develop distinctly the more robust plants; the effect has clearly been due to the greater supply of nitrate. The net result has varied. On B7–8 there has been a statistically-significant difference in favour of 'digging-in' on four occasions, but more often the yields of the 'burnt' plots have been the greater, and this difference has also been statistically significant on four occasions.

For some years surface-soil samples were taken annually in these experiments, usually early in May. Doyne [13] reported on the analyses of samples taken early in May and early in December in 1936 in Field B7–8. He found that the 'burnt' plots had the higher pH value and exchangeable-base content, and in May a greater content of soluble salts other than nitrate; and that the 'dug-in' plots contained higher amounts of total nitrogen and nitrates. He remarked, however, that the amount of nitrates in the burnt plots was considerable, and that it should be sufficient for the average crop. Similar differences to those reported by Doyne were found every year; the figures for nitrates are given in Table 8. It seems that in these experiments there has been sufficient nitrogenous matter added on the 'burnt' plots in leaf-fall during growth and in the roots and nodules left in the soil, to supply nitrate for a fair crop of early maize.

TABLE 8. *Field B7–8. Nitrate-content. Average of Determinations on Individual Plots*

Results expressed as nitrate-N in p.p.m.

| | 15/5/35 | 24/7/35 | 1/5/36 | 13/5/36 | 30/4/37 | 6/5/38 | 2/5/39 | 10/5/40 | 19/5/41 | 26/5/42 | 24/5/43 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dug in plots . | 25 | 4 | 142 | 108 | 81 | 101 | 76 | 77 | 75 | 70 | 35 |
| Burnt plots . . | 9 | 2 | 80 | 57 | 58 | 46 | 53 | 38 | 21 | 31 | 5 |

Taking the samples early in May did not give a true picture of the general level of nitrate supply on the 'burnt' plots. Work reported by Wright [15], Diamond and Hartley [16], and Diamond [14] had shown that the nitrate-content was at a peak at about this time, and that a rapid decrease occurred as heavy rains continued during May and June. The figures for Field B7–8 for May 15, 1935 and May 24, 1943 gave an indication that the decrease in nitrate-content after the peak in early May might be relatively greater on the 'burnt' than on the 'dug-in' plots, and that there was likely to be a deficiency in nitrate supply on the 'burnt' plots during the later stages of growth of the maize.

From April 1947 to March 1948 surface samples were taken once a fortnight in Field B7–8 for nitrate determinations. The results are given in Table 9, and these show a great difference between the two sets of plots. During the period June 4–August 13 the average nitrate-N on the 'dug in' plots was 24·5 p.p.m., compared with 1·3 p.p.m. on 'burnt' plots.

It now seems unfortunate that the comparison between digging in mucuna and burning it was made the subject of separate experiments and not superimposed on the rotation experiments described earlier in this paper, in which serious nitrate deficiency appeared, and where digging-in of green manures would probably have been found markedly superior to burning, especially in the cases of crops other than early maize, which may be able to obtain most of its nitrogen requirement during the nitrate-peak in April–May.

TABLE 9. *Field B7–8. Determinations of Total Nitrogen and Nitrate-Nitrogen, 1947–8*

| | *Rainfall in previous fortnight (inches)* | *Total nitrogen (per cent.)* | | *Nitrate-N (p.p.m.)* | |
|---|---|---|---|---|---|
| | | *Dug-in plots* | *Burnt plots* | *Dug-in plots* | *Burnt plots* |
| *1947* | | | | | |
| Apr. 9 | .. | .. | .. | .. | .. |
| Apr. 23 | 2·17 | .. | .. | 59·9 | 32·1 |
| May 7 | 2·78 | 0·101 | 0·075 | 80·4 | 30·4 |
| May 21 | 4·46 | 0·1015 | 0·070 | 90·1 | 11·6 |
| June 4 | 3·24 | 0·0965 | 0·070 | 59·4 | 1·7 |
| June 18 | 2·29 | 0·101 | 0·0695 | 42·5 | 0·65 |
| July 2 | 1·79 | 0·098 | 0·071 | 15·1 | 0·55 |
| July 16 | 4·25 | 0·097 | 0·0685 | 9·9 | 0·9 |
| July 30 | 1·30 | 0·0965 | 0·073 | 7·3 | 1·6 |
| Aug. 13 | 1·84 | 0·091 | 0·073 | 13·0 | 2·2 |
| Aug. 27 | 6·36 | 0·089 | 0·0725 | 2·2 | 0·7 |
| Sept. 10 | 12·07 | 0·084 | 0·069 | 1·0 | 0·5 |
| Sept. 24 | 7·85 | .. | .. | 0·9 | 0·5 |
| Oct. 8 | 6·35 | 0·084 | 0·067 | 1·3 | 0·6 |
| Oct. 22 | 2·44 | 0·084 | 0·0705 | 2·3 | 1·2 |
| Nov. 5 | 0·41 | 0·085 | 0·0745 | 3·1 | 1·5 |
| Nov. 19 | 0·31 | 0·0845 | 0·0665 | 5·1 | 2·1 |
| Dec. 3 | 0·89 | 0·081 | 0·0705 | 10·6 | 6·6 |
| Dec. 17 | 0·67 | 0·0825 | 0·070 | 18·4 | 12·1 |
| Dec. 31 | 0·00 | 0·084 | 0·0665 | 20·6 | 14·4 |
| *1948* | | | | | |
| Jan. 14 | 0·00 | .. | .. | 30·0 | 21·8 |
| Jan. 28 | 0·00 | .. | .. | 40·6 | 23·4 |
| Feb. 11 | 0·00 | .. | .. | 40·0 | 27·0 |
| Feb. 25 | 1·96 | .. | .. | 48·9 | 32·5 |
| Mar. 10 | 0·30 | .. | .. | 46·6 | 25·0 |
| Mar. 24 | 1·33 | .. | .. | 48·6 | 22·0 |

The figures for total nitrogen from May to December are included in Table 9. It is noteworthy that these show no change, in the case of the 'burnt' plots, whilst on the 'dug-in' plots there was a gradual disappearance of 0·016 per cent. of nitrogen, equivalent to about 125 lb. of nitrogen per acre, between May and September; this amount of nitrogen is approximately that contained in an average mucuna crop on Moor Plantation (about 6,000 lb. of dry matter in leaves and stems, containing about 2·0 per cent. nitrogen).

The following figures for total-nitrogen content over a period of 12 years on Field B7–8 are also noteworthy:

| | *Dug-in plots* | *Burnt plots* |
|---|---|---|
| Average of May 15, 1935, May 1, 1936, April 30, 1937 | 0·095 | 0·079 |
| " " May 6, 1938, May 2, 1939, May 10, 1940 | 0·098 | 0·081 |
| " " May 19, 1941, May 26, 1942, May 24, 1943 | 0·094 | 0·073 |
| " " May and June samples, 1947 | 0·100 | 0·071 |

These figures show no definite increase in nitrogen-content on the 'dug-in' plots, and only a slight decrease on the 'burnt' plots.

The experiment on Field A5S already described was followed up after 3 years of uniform cropping by a further comparison between the three former treatments of mucuna, using a layout of plots in randomized blocks. Starting with the early maize crop of 1946, the plots were divided into sub-plots for applications of farmyard manure; (well-rotted manure was used, at the rate of 2 t. per acre). Yams were grown in 1948 and 1951; the 1950 early maize crop was a failure, on account of Army Worm and Rust attack. Omitting yields of sub-plots having manure applied to the mucuna instead of to the maize, the yields of early maize in 1946, 1947, and 1949 were as follows:

| | *Mucuna dug in green* | | *Mucuna burnt* | | *Mucuna cut and carried off* | |
|---|---|---|---|---|---|---|
| | *No manure* | *2 tons f.y.m. per acre* | *No manure* | *2 tons f.y.m. per acre* | *No manure* | *2 tons f.y.m. per acre* |
| 1946 | 882 | 1,152 | 1,156 | 1,351 | 668 | 1,158 |
| 1947 | 812 | 1,309 | 806 | 1,111 | 563 | 1,076 |
| 1949 | 1,376 | 2,063 | 1,237 | 1,721 | 1,209 | 1,641 |
| Average | 1,023 | 1,508 | 1,066 | 1,394 | 813 | 1,292 |

As in the earlier experiment (see Table 7) no consistent difference in maize yields appeared between 'dug-in' and 'burnt' plots, whilst there was by comparison a loss of 200 to 300 lb. per acre on 'cut-and-carried-off' plots. On the other hand, the farmyard-manure dressing gave an increase in yield of about twice this amount. The field has always given relatively low yields, and a minor experiment on spare strips along the edge has indicated a more marked deficiency of phosphate here than on most fields on Moor Plantation, whilst nitrate deficiency has also been apparent. The comparatively small loss of yield from cutting and carrying off the mucuna in these conditions, whilst farmyard manure has been more effective than in other experiments at Moor Plantation, is an indication that the manurial value of the mucuna crop is not great.

*Some general observations.*—It is now evident that on these soils increasing the organic-matter content is dependent on having fallow periods under dense vegetative growth for a longer time than that for which mucuna covers the ground. Some preliminary experiments with restorative fallows have been done, and more systematic experiments are to be started. Excellent results are likely to be obtained from the use of mixtures of *Centrosema pubescens* Benth. (a creeping leguminous plant) with certain grasses (notably *Cenchrus* sp.) which have been established in recent years here. Probably the alternation of a 3-years' resting period under such a cover, with 6 years of rotational cropping, will be found practicable.

It is particularly important to have demonstrated that these soils are capable of being very productive under intensive cropping, now that the introduction of modern methods of mechanized farming is being

considered. The suggested alternation of cropping and grass-legume fallow would be very appropriate to mechanization.

Sulphate of ammonia has given very profitable increases of yield in recent experiments on the fields which have been continuously cultivated for many years. During the past 12 years, however, the local market prices of foodstuffs have risen to several times what they were previously, whilst the cost of fertilizers has increased much less in proportion, and it is doubtful whether sulphate of ammonia would have given economic returns during the 1930's. In that period, therefore, there was a good case for growing mucuna in rotations, as a source of nitrogen for the crop immediately following it. At present the use of nitrogenous fertilizer, without green manures, seems to be more economic.

It is necessary to consider what suggestions can be made for the improvement of local farming methods, dependent on hand-cultivation only. In places where a good cover of bushy growth regenerates after each period of cropping (which depends on the roots and stumps of trees and bushes not being killed out) good crops are obtained, and it is very doubtful whether farmers should be recommended to make any change. Where regrowth is of savannah or transitional types yields could generally be improved by means of some use of mucuna or lima beans and increased growing of cowpeas. Much might be achieved if the people could be persuaded to place restrictions on the cutting of poles and firewood in fallow land, and on indiscriminate burning, thus preventing much of the deterioration to savannah, and planting of trees for which coppice might well be useful.

Griffith [17] has obtained remarkable results in studies of the effects of mulching (with grass) on soil-nitrate formation, in Uganda. Mulching was found to reduce the formation of nitrate very considerably, but almost the same effect was obtained by means of overhead shade. It seems possible that, conversely, the building up of the amount of humus in the soil is dependent on shade in these tropical conditions. If this is so, the failure of short-term green manures to increase the humus content is understandable, and there is reason to expect longer-term fallow covers to be much more effective.

*Acknowledgements.*—The experimental work at Moor Plantation has been carried out under the direction of Mr. O. T. Faulkner and Capt. J. R. Mackie, former Directors of Agriculture, and Mr. A. G. Beattie, the present Inspector-General, to whom the writer is grateful for permission to publish this account. It is impossible to refer to all who have taken part in the work, but the writer wishes to acknowledge his indebtedness to staff of the Chemistry Section for doing the analytical work, and to Mr. W. E. Freeman, Mr. P. H. Nye, and others for criticism during the writing of this paper.

## REFERENCES

1. C. J. Lewin, Agric. Dept., Nigeria, 1931, 3rd Special Bulletin.
2. O. T. Faulkner, Empire J. Expt. Agric., 1934, **2**, 93.
3. C. C. Webster, 3rd W. Afr. Agric. Conf. Papers (Nigeria), 1938, pp. 299–321.

4. F. E. Buckley, ibid., pp. 61–74.
5. Agric. Dept., Nigeria, 1953, Special Bulletin.
6. H. C. Doyne, K. T. Hartley, and W. A. Watson, 3rd W. Afr. Agric. Conf. Papers (Nigeria), 1938, pp. 227–98.
7. R. W. J. Keay, An Outline of Nigerian Vegetation, Nigerian Govt., Lagos, 1949.
8. H. C. Doyne, J. Agric. Sci., 1935, **25**, 192.
9. F. Hardy and E. H. Amoroso-Centeno, 7th Ann. Rept. Cacao Research, I.C.T.A. Trinidad, 1937, p. 33.
10. P. Nye, Empire J. Expt. Agric., 1951, **19**, 275–82.
11. —— Ibid., 1952, **20**, 47–55.
12. D. Rhind, J. M. Waterston, and D. C. Deighton, Nature, 1952, **169**, 631.
13. H. C. Doyne, Empire J. Expt. Agric., 1937, **5**, 248.
14. W. E. de B. Diamond, ibid., 264.
15. C. H. Wright, Agric. Dept., Nigeria, 1929, 8th Annual Bulletin, pp. 104–9.
16. W. E. de B. Diamond and K. T. Hartley, Agric. Dept., Nigeria, 1930, 9th Annual Bulletin, pp. 27–34.
17. G. ap Griffith, Empire J. Expt. Agric., 1951, **19**, 1–12.

(*Received September 3, 1952*)

# THE REGENERATION OF SOIL HUMUS UNDER A GRASS LEY

J. J. THERON AND D. G. HAYLETT
(*Faculty of Agriculture, University of Pretoria*)

IN the summer-rainfall areas of the Union of South Africa dryland agriculture has been practised for the past 50–75 years. Yields were generally low but were satisfactorily maintained with the assistance of phosphatic fertilizers. In recent years, however, retrogression in productivity is becoming increasingly evident and is causing concern. The loss of top-soil through erosion is undoubtedly the main immediate cause of the retrogression, but evidently the depletion of organic matter occasioned by the repeated tillage, which the production of annual crops entails, is the factor basically responsible.

The climatic and environmental conditions of these areas are very conducive to the mineralization of organic matter. A rapid impoverishment of the ploughed soil, followed by deterioration of soil structure, is thus to be expected, and the widespread havoc wrought by wind and water erosion in the short period of our agricultural history emphasizes the rapidity of this process of impoverishment [1].

The introduction of rotations that include a perennial grass crop under which the soil 'rests' from cultivation for a period of years has therefore been widely advocated in recent years. But whilst grass crops may afford mechanical protection and may re-establish crumb structure they cannot regenerate the soil humus unless provision is made for nitrogen in order to maintain the characteristically constant C/N ratio. Unless humus is regenerated the improvement in structure can only be very transient.

In the humid temperate areas perennial legumes (e.g. clovers) growing with the grass furnish the required nitrogen by symbiotic fixation but, under dryland conditions locally, clovers have not proved successful, and no other legume has been found that will grow successfully with the grass. The main supply of nitrogen will thus have to come from nitrogenous fertilizers. The efficacy of this source of nitrogen for humus regeneration under a grass pasture established on an old land is discussed in this paper. A more detailed account of the results of the field trials dealing more specifically with the agronomic aspects of the experiment is reported elsewhere [2].

*Experimental procedure.*—During the latter part of the 1940–1 season Rhodes grass (*Chloris gayana*) was sown on a field which had been under cultivation to annual crops for about 17 years, and in November 1941 a fertilizer experiment was laid down on the established pasture. The plots used were approximately 0·01 morgen[1] in area. The fertilizer treatments were arranged factorially involving three levels of phosphate and four levels of nitrogen. Superphosphate containing 18–18·5 per cent.

[1] One morgen = 2·116 English acres.

[Empire Journ. of Exper. Agric., Vol. 21, No. 82, 1953.]

water-soluble $P_2O_5$ and ammonium sulphate were used, being applied annually at the following rates per morgen:

Superphosphate: Po = nil, P1 = 600 lb., P2 = 1,200 lb.
Ammonium sulphate: No = nil, N1 = 500 lb., N2 = 1,000 lb. N3 = 2,000 lb.

The twelve treatment combinations were each replicated four times. The superphosphate was applied in November in one application and the ammonium sulphate in three equal quantities in November, January, and March. Since previous trials on this soil type had shown no response from grass or crops to applications of potash, no potash treatments were included in the experiment. A sufficiency of potash in the soil is commonly found in the great majority of soils throughout the summer-rainfall areas of the Union of South Africa [3, 4].

The response to the fertilizer treatments was measured by obtaining the yield as well as the contents of crude protein and phosphorus of the air-dry hay. Samples were taken at each cutting, of which there were usually three per season.

Although the field was originally sown to Rhodes grass this grass could not maintain itself on the plots that were fertilized with sulphate of ammonia. On these it was rapidly displaced by *Paspalum dilatatum*, which multiplied from seeds of stray plants. The experimental sward thus actually consisted of a nearly pure stand of Rhodes grass on those plots that received no ammonium sulphate and a nearly pure stand of Paspalum on all plots receiving the high nitrogen applications.

During the winter of 1948, after the grass had occupied the soil for seven seasons, it was ploughed up and the plots used for growing maize. Samples of soil were collected from each plot shortly before the soil was ploughed.

### *Experimental Results*

The average annual yield of hay and the data in respect of the contents of protein and phosphoric oxide are summarized in Tables 1, 2, and 3. The averages were calculated from the yields of six seasons only, since one cutting, during the 1946–7 season, was lost owing to the grass being accidentally grazed off by animals; the results for this season were therefore discarded. The season was, however, reasonably 'normal', and its exclusion should therefore not introduce a serious error if the averages for the six seasons are taken to represent the entire period of the experiment.

The data in Table 1 show that marked increases in yields were obtained with the application of nitrogen; phosphate was definitely of secondary importance, and there was no advantage to be gained by the higher rate of application of the superphosphate, i.e. of the P2 treatment over the P1 treatment. In fact, although the phosphate means show significant responses, this was due to an interaction of the phosphate solely with the N3 but not with the N1 or N2 treatments. Only when the yield of hay is increased to 6 t. per morgen, i.e. four to fivefold, is the soil not able to mobilize sufficient phosphate from its own reserves to

TABLE 1. *Average Annual Yield of Air-dry Hay in Tons per Morgen for Six Seasons*

| *Treatments* | No | N1 | N2 | N3 | *Phosphate means* |
|---|---|---|---|---|---|
| Po | 1·45* | 2·45 | 3·70 | 4·91 | 3·13‡ |
| P1 | 1·78 | 2·48 | 3·69 | 6·04 | 3·50 |
| P2 | 1·81 | 2·53 | 3·89 | 6·41 | 3·66 |
| N-means | 1·68† | 2·49 | 3·76 | 5·79 | 3·43 |

Minimum differences significant (M.D.S.) at P = 0·05:
* For individual treatments (24 vs. 24 plots): 0·46 tons
† ,, nitrogen means (72 vs. 72 ,, ): 0·26 ,,
‡ ,, phosphate means (96 vs. 96 ,, ): 0·23 ,,

supply the needs of the crop. The maximum quantity that the soil could mobilize was 21 lb. of $P_2O_5$ per morgen in the PoN3 treatment and the yield was limited to the herbage that could be produced with this quantity of phosphate. Approximately double this amount, viz. 39·4 and 43·6 lb. of $P_2O_5$, was taken up by the crops on the P1N3 and P2N3 plots respectively (see Table 3).

The percentages and yields of crude protein given in Table 2 likewise show a marked response to nitrogen, but not to phosphate except again for the phosphate × N3 interaction.

TABLE 2. *Average Percentages and Yields in Pounds of Crude Protein per Morgen in the Air-dry Hay for Six Seasons*

| | *Percentage crude protein* | | | | | *Yield of crude protein* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Treatments* | No | N1 | N2 | N3 | P-*means* | No | N1 | N2 | N3 | P-*means* |
| Po | 4·99* | 5·36 | 6·40 | 8·35 | 6·27‡ | 154* | 264 | 456 | 761 | 409‡ |
| P1 | 4·81 | 5·31 | 6·14 | 8·26 | 6·13 | 190 | 269 | 441 | 927 | 457 |
| P2 | 5·09 | 5·35 | 5·83 | 8·63 | 6·23 | 197 | 284 | 446 | 1,011 | 484 |
| N-means | 4·96† | 5·34 | 6·12 | 8·41 | 6·21 | 180† | 272 | 448 | 900 | 445 |

M.D.S. at P = 0·05:
* For individual treatments (24 vs. 24 plots) = 0·55% and 51·2 lb.
† ,, nitrogen means (72 vs. 72 ,, ) = 0·32 ,, ,, 29·5 ,,
‡ ,, phosphate means (96 vs. 96 ,, ) = 0·27 ,, ,, 25·6 ,,

The sulphate of ammonia increased the protein-content of the hay from 4·96 to 8·41 per cent. and the yield of protein from 180 to 900 lb. per morgen. In fact, if the yields of the first season in which the mineralization of organic nitrogen still took place, as discussed below, are omitted, it appears that the increase was actually ninefold, i.e. from 100 to 900 lb. per morgen.

The application of superphosphate had no significant effect on the yield of hay or protein, but it brought about very significant increases in the percentage phosphate contained in the hay, as the data in Table 3 show. Increases were also obtained in the total yield of $P_2O_5$ per unit

area. The higher rate of application was superior to the lower in both these respects.

TABLE 3. *Average Percentages and Yields of* $P_2O_5$ *in the Air-dry Hay for Six Seasons*

| | *Percentage* $P_2O_5$ | | | | | *Yields* $P_2O_5$ *lb. per morgen* | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Treatments* | No | N1 | N2 | N3 | P-*means* | No | N1 | N2 | N3 | P-*means* |
| Po | 0·33* | 0·30 | 0·25 | 0·23 | 0·28‡ | 9·0* | 14·3 | 17·1 | 21·0 | 15·4‡ |
| P1 | 0·40 | 0·41 | 0·35 | 0·34 | 0·38 | 13·0 | 19·7 | 25·4 | 39·4 | 24·4 |
| P2 | 0·44 | 0·42 | 0·38 | 0·36 | 0·40 | 14·9 | 20·9 | 28·1 | 43·6 | 26·9 |
| N-means | 0·39† | 0·37 | 0·33 | 0·31 | 0·35 | 12·3† | 18·3 | 23·6 | 34·7 | 22·2 |

M.D.S. at P = 0·05:

* For individual treatments (24 vs. 24 plots) = 0·03% and 2·29 lb.
† „ nitrogen means (72 vs. 72 „ ) = 0·01 „ „ 1·32 „
‡ „ phosphate means (96 vs. 96 „ ) = 0·01 „ „ 1·14 „

The nitrogen applications lowered the percentage of phosphoric oxide in the herbage and thereby probably also the palatability of the hay. The total quantity per morgen was, however, greatly increased, due to the greater yield of hay.

### *Effect of the Fertilized Grass on the Soil*

When the ley was ended in 1948, soil samples were taken from each plot with a Viehmeyer type of soil-tube, and to a depth of one foot. Owing to an underlying gravelly layer, deeper sampling was not attempted. Five borings were made per plot. The soil was rapidly dried, passed through a 2-mm. sieve, and stored in glass jars. Analyses for carbon by the dry-combustion method and nitrogen, including nitrates, by the Kjeldahl method were made on finely ground soil; the pH was determined on the unground samples with the glass electrode, only sufficient water being added to the dry soil to allow the paste to flow freely around the electrodes. The pH was determined after the moistened soil had stood for some time—usually overnight. The results of these analyses are summarized in Tables 4, 5, and 6.

*Carbon-content.*—The data in Table 4 show that the superphosphate had no effect on the carbon-content of the soil, but significant increases resulted from the application of sulphate of ammonia; a maximum was reached at the annual rate of application of 1,000 lb. per morgen.

The reason for the lower build-up on the N3 plots (relative to the N2 treatments) is not clear since the growth of grass and presumably also of the roots (i.e. the source of supply of carbonaceous matter) was much greater, and should therefore have resulted in a larger increase in organic matter in the soil of the N3 than of the N2 plots. This behaviour may have been due to the high degree of acidification resulting from the heavy applications of the sulphate of ammonia (see Table 6).

Unfortunately, samples were not obtained from the soil when the experiment was started, and thus the data do not give a clear picture of the extent to which organic matter may have been built up under the

TABLE 4. *Influence of Fertilizers on the Percentage of Organic Carbon in the Surface-foot of Air-dry Soil*

| *Treatments* | No | N1 | N2 | N3 | P-*means* |
|---|---|---|---|---|---|
| Po | 1·585* | 1·639 | 1·754 | 1·633 | 1·660‡ |
| P1 | 1·585 | 1·598 | 1·739 | 1·653 | 1·644 |
| P2 | 1·655 | 1·730 | 1·756 | 1·676 | 1·704 |
| N-means | 1·608† | 1·656 | 1·750 | 1·654 | 1·669 |

M.D.S. at P = 0·05:

* Between individual treatments (4 vs. 4 plots) = 0·115%
† ,, N-means (12 vs. 12 ,, ) = 0·066 ,,
‡ ,, P-means (16 vs. 16 ,, ) = 0·057 ,,

unfertilized grass, but it seems unlikely that any material increase could have taken place on the No plots since they received no nitrogen. On the contrary, nitrogen was regularly removed in the hay and consequently some loss of humus may have taken place. However, relative to the No treatment, replenishment of organic matter took place in fair measure as a direct result of the nitrogen applied in the sulphate of ammonia. The average increase of carbon on the N2 plots, namely 0·142 per cent. in 7 years, amounts to an annual increment of approximately 1½ t. of organic matter per morgen in the surface-foot, with probably some also in the lower layers. This is nearly double the rate of build-up reported by Penman [5] under subterranean clover in Australia.

Reference to Table 5 shows that again the application of superphosphate had no influence on the nitrogen-content of the soil, but as expected the use of sulphate of ammonia resulted in very significant increases of soil nitrogen; the increases were maintained up to the highest level of application tested. The recession in the carbon build-up in the N3 plots was thus not due to a lack of nitrogen in the soil.

TABLE 5. *Effects of Fertilizers on the Nitrogen-content of the Surface-foot of Soil expressed as Percentages of the Air-dry Soil*

| *Treatments* | No | N1 | N2 | N3 | P-*means* |
|---|---|---|---|---|---|
| Po | 0·103* | 0·109 | 0·112 | 0·123 | 0·112‡ |
| P1 | 0·107 | 0·109 | 0·115 | 0·112 | 0·110 |
| P2 | 0·106 | 0·112 | 0·113 | 0·117 | 0·112 |
| N-means | 0·105† | 0·110 | 0·113 | 0·117 | 0·111 |

M.D.S. at P = 0·05:

* Between individual means (4 vs. 4 plots) = 0·007%
† ,, N-means (12 vs. 12 ,, ) = 0·004 ,,
‡ ,, P-means (16 vs. 16 ,, ) = 0·003 ,,

The data in respect of the influence of the fertilizers on the reaction of the soil are summarized in Table 6.

Acidification of the surface-soil is clearly evident; the reaction of the soil was lowered by more than one unit of pH, namely, from 5·36 for

TABLE 6. *Effect of Fertilizers on the pH of the Soil**

| *Treatments* | No | N1 | N2 | N3 | P-*means* |
|---|---|---|---|---|---|
| Po | 5·36 | 4·83 | 4·60 | 4·17 | 4·55 |
| P1 | 5·36 | 5·06 | 4·66 | 4·19 | 4·60 |
| P2 | 5·35 | 4·93 | 4·88 | 4·24 | 4·60 |
| N-means | 5·36 | 4·93 | 4·61 | 4·20 | 4·59 |

* The average pH values were calculated by converting the pH of each sample to H-ion concentration and using the reaction values so obtained.

No to 4·20 for the N3 treatments. The superphosphate had evidently no appreciable influence on the reaction.

## *Discussion*

In a previous paper Theron [6] outlined what are believed to be the principles on which the restoration of the organic matter by means of perennial grass crops should be based. In this paper the view was expressed that the living roots of plants inhibit nitrification, and thereby prevent the loss of nitrogen from the soil; and hence, owing to the constancy of the C/N ratio in the soil, the loss of organic matter is also prevented. When a perennial grass is thus established on a soil that has previously been under cultivation, the mineralization of organic matter, which took place freely under the annual crops, is inhibited as soon as the soil is fully occupied by the grass roots. From then onwards the building-up of humus becomes possible in the soil.

If the ley includes a legume (e.g. clover) and symbiotic fixation is active, nitrogen from the atmosphere will be bound and a progressive build-up of humus will take place. In the absence of such a source, nitrogen may accrue to the soil by asymbiotic fixation and in small amounts from the atmosphere, but it is unlikely that the free-living nitrogen-fixing organisms do in fact bind appreciable amounts of nitrogen under a perennial grass crop owing to the relatively high concentration of ammonia present in the soil under the grass [6]. Cornish [7] expressed similar views in regard to asymbiotic fixation under Australian conditions.

Nitrogenous fertilizers are the only alternative sources of nitrogen of any consequence. In the absence of a suitable legume growing with the grass, the use of these fertilizers seems to be imperative if the ley is to fulfil its most important function, namely the rebuilding of the humus and thereby the soil structure. The results of the experiment described above throw some light on several aspects of this important problem.

*Period of the ley.*—The number of years that the soil should be left under pasture is of great practical importance. The period under grass must be long enough not only to enable the desirable crumb structure to be regained but also to enable the soil to accumulate sufficient organic matter to provide for mineralization during the next arable period. Crumb structure is apparently readily regained under a grass cover, but improvement in physical condition will be short lived unless the organic

matter on which the stability of the crumbs largely depends is also built up.

In this connexion the data relative to the nitrogen recovered in the crops is of interest since the quantity of nitrogen available to, and absorbed by, the grass reflects the organic matter relationships in the soil. In Fig. 1 the yields of crude protein (N × 6·25) for each nitrogen treatment are plotted against the seasons. From these graphs it is evident that in

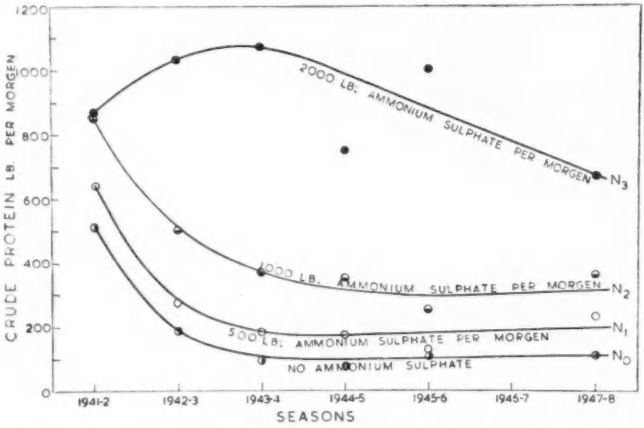



FIG. 1. Average seasonal production of crude protein, with different quantities of ammonium sulphate.

respect of the No, N1, and N2 treatments relatively large quantities of nitrogen were released from the stores of the soil during the first season and luxuriant growth took place on all plots. Thus the No treatment yielded 513 lb. of protein during the first season. The yield of protein declined rapidly and during the last five seasons it fell to a value fluctuating around an annual yield of about 100 lb. per morgen—only one-fifth of the yield recorded during the first season. The hay yield of the No treatment showed a similar trend, and by the third season the sward presented a very unthrifty appearance indicative of severe nitrogen starvation; the decline was from 3·75 t. in the first season to an average of approximately 1 t. during the last five.

The same trends are revealed by the curves representing the N1 and N2 treatments, but the curve for the N3 treatment is of an entirely different character. The probable reason for this will be discussed below.

The downward trend in hay and protein production is not due to a depletion of nitrogen, in the ordinary sense. This can be readily demonstrated by ploughing up such a sward when it has reached the unthrifty condition and replanting it with the same grass. It will then be found that the luxuriant-growth characteristic of the first season is again obtained for a season or two, but the vigour of growth soon declines.

Similarly, if the ploughed-up sward is replaced by an annual crop, a deficiency of nitrogen is not experienced, and no decline in yield comparable with that shown by a perennial grass crop is found. On the contrary a marked response of arable crops to applications of phosphates usually develops. In the present experiment the No plots were producing very satisfactory crops of maize, and showed no lack of nitrogen three seasons after the grass, which showed such obvious signs of nitrogen starvation, was ploughed up.

The good growth in the first season, particularly on the unfertilized plots, evidently takes place at the expense of the reserves of nitrogen and organic matter in the soil; mineralization, similar to that which takes place under arable cropping, is not checked completely by the grass until towards the end of the second season. The first crop of grass is thus no less exploitive than the ordinary annual crops, and it is only when, and to the extent that, the mineralization is brought under control by the grass that the loss of organic matter is inhibited. Only then can rebuilding be expected to take place. Humus synthesis may, of course, be initiated in the upper layers during the latter part of the first season or beginning of the second, as soon as these parts of the soil are adequately occupied by roots, but from the results reported above it would appear that the complete inhibition of mineralization is brought about only towards the end of the second season.

The duration of the ley should therefore be at least three seasons, and preferably longer, for any material increase in organic matter to take place. Unfortunately the present experiment does not give any reliable indication of either the actual time of commencement or the rate of build-up, particularly in relation to the quantities of nitrogen applied. Further experiments to study these aspects are being planned.

Penman [5] in Australia found no appreciable build-up of soil nitrogen within 3 years after sowing subterranean clover leys. Only after 3 years with suitable top-dressings of phosphates did organic matter and nitrogen begin to accumulate in the soil. In view of this he suggested that 8–10 years under the ley would be desirable to allow for the slow start and the possibility of a few poor years. Our results agree with his findings, but it would appear that the build-up can be greatly accelerated after the second year, and the period of the ley considerably reduced, by applications of nitrogen. In the N2 treatments of our experiment the build-up was considerably in excess of the 4 t. of organic matter per acre in 10 years which Penman reports.

*Utilization of the applied nitrogen.*—As mentioned above, signs of nitrogen starvation appeared in the grass as soon as the mineralization of the organic matter present in the soil was inhibited, and marked responses to heavy applications of nitrogen were then obtained. As is evident from the curves in Figs. 2 and 3, the response in respect of the average annual yield of hay and protein for the latter four seasons of the experiment, to applications of nitrogen, fell distinctly short of the maximum possible, even with the heaviest application tested, viz. 2,000 lb. ammonium sulphate per morgen. It would appear thus that not only is the availability of the nitrogen naturally present in the soil depressed

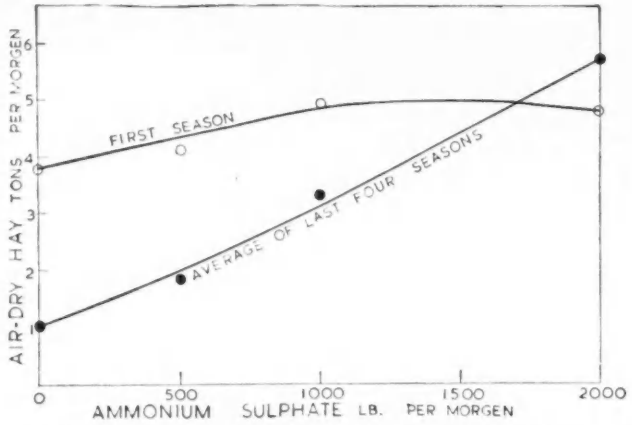



FIG. 2. Effect of ammonium sulphate applications on air-dry hay yields.

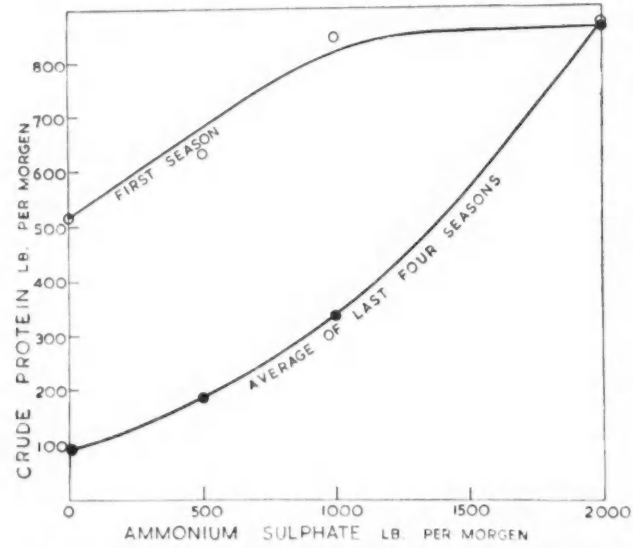



FIG. 3. Effect of ammonium sulphate on yields of crude protein.

to a minimum by the perennial, but also that the nitrogen added as fertilizer is retained and bound by the soil so tenaciously that very large quantities in excess are required to supply the needs of the crop for maximum growth. Evidently the added nitrogen is largely utilized in rebuilding the organic matter of the soil. It is of interest to determine

how the applied nitrogen is distributed between the soil and the herbage above ground. The data given in Table 7 throw light on this question.

TABLE 7. *Nitrogen Balance Sheet in Pounds per Morgen*

| *Treatment* | | No | N1 | N2 | N3 |
|---|---|---|---|---|---|
| N found in surface-foot of $9 \times 10^6$ lb. of soil (lb.) | | 9,450 | 9,900 | 10,170 | 10,530 |
| N recovered in seven crops (lb.) . . . | | 202 | 305 | 501 | 1,008 |
| Total N applied in seven seasons (lb.) . . | | . . | 700 | 1,400 | 2,800 |
| Percentage of N applied | recovered in crops . | . . | 15 | 21 | 29 |
| | found in surface-foot of soil . . | . . | 64 | 51 | 39 |
| | not accounted for . | . . | 21 | 28 | 32 |

The percentage recoveries were calculated on the assumption that during the seven seasons an average of 202 lb. of nitrogen per morgen—the quantity found under the No treatment—would be mobilized from the soil reserves on all plots irrespective of the treatments.

The calculated quantities of nitrogen found in the soil are subject to serious magnification of the sampling and analytical errors, due to the high conversion factor of $9 \times 10^6$. These figures should therefore be accepted with reserve; they do, however, seem to indicate that a considerable part of the applied nitrogen is retained by the soil, and that a part, possibly the greater part, of the nitrogen not accounted for may be found in the lower layers of soil.

In view of the constant C/N ratio maintained by the soil, the nitrogen found there is clearly retained in the organic form. The $NH_4$-ion is probably absorbed initially on the negatively charged colloidal complex, but in time is incorporated biologically in the humus by root and microbial action. Since the $NO_3$-ion is not absorbed by the soil, the use of nitrates instead of ammonium salts as sources of nitrogen may give different results.

In the nitrogen balance sheet the lower the rate of application of nitrogen the lower is the percentage recovery in the crops and the higher the retention in the soil. Thus it would appear that when light applications are given the nitrogen is utilized in the first instance to rebuild the soil humus, and the carbon that is assimilated from the atmosphere by the plants is transferred to the soil in preference to being used to increase the bulk of hay. This transfer takes place mainly for producing root-tissue, and when there is little nitrogen available in the soil, root-growth seems to be favoured relative to the growth of aerial parts. This accounts for the accumulation of organic matter in the soil, apparently at the expense of herbage production.

When assessed by hay production the response of grass to relatively light applications of nitrogen (40–60 lb. per morgen) often appears very disappointing; but if such a pasture is intensively grazed marked gains in live-weight are usually reflected by the grazing animals. This paradox

is due to the fact that the grass, in being continuously defoliated, is not afforded the opportunity to accumulate carbon in the soil to combine with the nitrogen that is applied. The latter thus remains available for the production of proteins in the herbage to the direct advantage of the grazing animal. In effect, the applied nitrogen is thus transferred as protein from the soil to the animal.

On the other hand, when the grass is not grazed off, the carbon assimilated by photosynthetic activity is used largely for root-growth without showing a corresponding increase in the bulk of the aerial parts. The nitrogen is thus retained in the soil and ultimately incorporated in the humus. The implications of such a course of events must be given careful consideration in planning the utilization of grass leys by grazing animals. Intensive short grazing of a ley may result in a heavy drain not only of nitrogen applied as fertilizer but also of nitrogen normally present in the soil, and the injudicious use of the animal may thus prevent the regeneration of organic matter and defeat the main object of the ley.

In the experiment described above it was only when the demands for nitrogen for the regeneration of humus were fully satisfied by the relatively heavy applications of the N3 treatment that the unhampered production of herbage could take place. The curves in Fig. 1 point to this conclusion; the shape of the curve for the N3 treatment reflects a set of growth conditions differing materially from those which existed on the No, N1, and N2 plots.

These conclusions are supported by the results of another experiment as follows: An analysis of a fertilized virgin pasture in the vicinity of the experiment under consideration showed that after five annual applications of sulphate of ammonia no increase in organic matter had taken place. In the virgin soil there was presumably no need for regenerating organic matter which had reached the maximum quantity the soil could hold. On this soil the recovery of the applied nitrogen was as follows:

| | | | | | |
|---|---|---|---|---|---|
| Nitrogen applied annually (lb.) . . | Nil | 200 | 400 | 600 | 800 |
| Nitrogen recovered in hay annually (lb.) | 23 | 102 | 186 | 224 | 256 |
| Recovery percentage . . . . | .. | 40 | 41 | 33 | 29 |

The nitrogen was applied as sulphate of ammonia at the rates of nil, 1,000, 2,000, 3,000, and 4,000 lb. per morgen annually.

On the virgin soil, contrary to what took place under the ley, proportionately more of the applied nitrogen was recovered at the lower than at the higher rates of application. At the two comparable rates, namely 1,000 and 2,000 lb. of sulphate of ammonia per morgen annually (200 and 400 lb. of N), 40 and 41 per cent. were recovered in the hay of the virgin pasture as compared with only 21 and 29 per cent. respectively in the hay of the ley crop. The greater tendency for nitrogen to be retained by the depleted soil under the artificial pasture is thus clearly evident.

*Quantity of nitrogen required.*—From the results presented above it appears that large quantities of nitrogen are required to regenerate the

organic matter in soils that have been depleted by cultivation. Within certain limits the rate of build-up will be determined by the quantity applied. The extent to which the soil has been depleted is also a factor in determining the optimal quantities required annually, but in actual practice the rate of application will be limited largely by economic considerations. To induce the agriculturalist to use fertilizers on the ley, the value of the increases in yields obtained thereby will naturally have to be more or less commensurate with the cost of the fertilizer. It is, however, not only the visible benefits (e.g. the larger quantities and better quality of hay produced) that should be taken into consideration, but also the increases in organic matter and the improvement in soil structure and stability. Another consideration is that the nitrogen which is temporarily immobilized in the humus will be released when the soil is again brought under cultivation. The cost of the fertilizer should therefore be debited, in part, to the arable crops following on the ley.

As mentioned above, although light applications of 40–60 lb. of nitrogen per morgen, such as are likely to be used in farming practice, would probably not produce very great increases in hay yields, the soil would nevertheless derive a real benefit, provided the ley were not over intensively used. Heavier applications will of course result in greater increases in herbage production and give a more rapid build-up of humus. Thus in the $N_2$-treatment the relatively heavy application of nitrogen (200 lb. per morgen annually) resulted in substantial increases in yields of both hay and protein, and also in a very satisfactory build-up of organic matter, but the latter advantage would have to be very highly valued to make up for the difference between the value of the herbage and the cost of the fertilizer.

The maximum yields were not reached, as is evident from Figs. 2 and 3, by the application of 2,000 lb. of sulphate of ammonia per morgen annually. Except for the cost, larger quantities could have been used to advantage. No corresponding increase in organic matter was, however, obtained over and above that resulting from the application of 1,000 lb. per morgen but, as mentioned previously, the relationship between humus regeneration and nitrogen applied may have been entirely distorted by the acidity that developed at the higher rates of application. The data therefore leave one in doubt as to the benefits that might have accrued to the soil if undesirable secondary effects had been eliminated. If, for example, acidity had been counteracted by the use of lime.

In this experiment nitrogen was removed in the hay, but if the grass had been grazed off moderately (so as to give the plants the opportunity to transfer the necessary carbon to the soil in their roots) part of the nitrogen taken up by the herbage would have been returned to the soil in the droppings of the animals. The rate of humus regeneration might have been greatly accelerated thereby, and, provided the ley were intelligently grazed, relatively light applications of nitrogen may prove adequate since the nitrogen will gradually accumulate in the soil. Present indications are, however, that the optimum rate of regeneration will require an expenditure on nitrogenous fertilizers which cannot be justified at present prices. The high cost of nitrogen may thus prove the

main obstacle to the introduction of sound conservation farming systems in the summer-rainfall areas of South Africa.

*Summary*

The rapid loss of organic matter under annual cropping has necessitated the introduction of grass leys in dryland farming in South Africa, but this practice suffers seriously from the drawback that no legume has been found to grow satisfactorily with the grass. The use of nitrogenous fertilizers as an alternate source of nitrogen was therefore investigated.

The maximum regeneration of humus was obtained from annual applications of 1,000 lb. of sulphate of ammonia per morgen, although hay yields were materially increased by still higher rates of application.

With light applications of sulphate of ammonia the greater part of the applied nitrogen was retained in the soil, the carbon assimilated from the atmosphere being evidently used for root-growth, and ultimately for humus regeneration, in preference to increasing the yield of herbage above ground. The role of the grazing animal is briefly discussed in the light of these observations.

From the results of this investigation it is concluded that, in the absence of a suitable legume, the grass ley can fulfil its essential purpose of replenishing the humus-content of a soil and regenerating its crumb structure, only if the grass occupies the soil for a period of more than 3 years, is not grazed excessively, and is in addition heavily manured with nitrogenous fertilizers.

REFERENCES

1. J. J. THERON, The Recuperation of the Soil under Grass Pastures. In *Grasses and Pastures of South Africa*. Edited by D. Meredith. Central News Agency, Johannesburg, South Africa. (In press.)
2. D. G. HAYLETT and J. J. THERON, Studies on the Fertilization of a Grass Ley. Bulletin, Dept. of Agriculture, Union of South Africa. (In press.)
3. T. D. HALL, D. MEREDITH, and S. M. MURRAY, Dry Matter and Protein of Pastures as affected by Amounts and Forms of Nitrogen applied. S.A. Jour. of Sci., 1947, **44**, 111–18.
4. —— —— and R. E. ALTONA, Production from Grasslands in South Africa. Fertilizer Treatments and Livestock Gains on Veld. Empire J. Expt. Agric., 1950, **18**, 69.
5. F. PENMAN, Effects on Victorian Soils of Various Crop-rotation Systems with Particular Reference to Changes in Nitrogen and Organic Matter under Cereal Cultivation. Brit. Com. Sci. Officials Conference, Australia, 1949. Session D: Soil Fertility.
6. J. J. THERON, The Influence of Plants on the Mineralization of Nitrogen and the Maintenance of Organic Matter in the Soil. J. Agric. Sci., 1951, **41**, 289–96.
7. E. A. CORNISH, Yield Trends in the Wheat-belt of South Australia 1896–1941. Austral. J. Sci. Res. Series B, 1949, **2**, 83–137.

(*Received November 14, 1952*)

# THE MANURING OF SUGAR-CANE

T. M. CAREY[1] AND P. ROBINSON[2]

MUCH experimental work has been carried out on the manuring of sugar-cane, but, for the most part, the results are given for isolated experiments and have not been collected into a comprehensive report. The results of experiments with potash in Jamaica, however, have recently been summarized by Innes and Chinloy [1], and further reports on the effect of nitrogen and phosphate are to be published. The experiments in this paper cover a much wider field. The first author (T. M. C.), while working in the Statistics Department at Rothamsted, extracted as many as possible of the published results of experiments in various territories of the British Commonwealth between about 1900 and 1943, and combined them into a comprehensive report, which was presented as a thesis to London University, and approved by the University for the award of a degree of Doctor of Philosophy. The contents of this thesis are presented here in a much abbreviated form. The original thesis is the sole responsibility of the first author (T. M. C.), whilst the second author (P. R.) has prepared the present summary, and is responsible for the section on sugar-content.

1. *The data.*—The number of experiments used in this report for each of the territories is given in Table 1, with a further subdivision into those experiments which were of a properly randomized design and those of a systematic design. The experiments may be roughly divided into three basic types. In the majority of the experiments the same or very similar differential treatments were applied to both plant-canes and ratoons. In this type of experiment the response of ratoons will be influenced by the residual effect of the fertilizers applied to the previous

TABLE 1. *Designs of the Experiments Abstracted for the Various Territories*

| *Territory* | *Systematic designs with 1–3 replications* | *Systematic designs with over 3 replications* | *Randomized designs* | *Total* |
|---|---|---|---|---|
| Jamaica | 93 | 1 | 32 | 126 |
| Trinidad | 3 | 6 | 45 | 54 |
| Barbados | 90 | 12 | 29 | 131 |
| St. Kitt's, Leeward Antigua Islands | 94 | 1 | 44 | 139 |
| | 104 | 2 | .. | 106 |
| British Guiana | .. | 34 | 187 | 221 |
| South Africa | 12 | 63 | .. | 75 |
| Mauritius | 68 | 44 | .. | 112 |
| India | 164 | 59 | 42 | 265 |
| Queensland | 52 | .. | 233 | 285 |
| Total | 680 | 222 | 612 | 1,514 |

[1] Professor of Statistics, Cork University.
[2] Statistician, East African Agriculture and Forestry Research Organization.

[Empire Journ. of Exper. Agric., Vol. 21, No. 82, 1953.]

crop. In a perennial crop like sugar-cane there is in addition to the ordinary residual effect of the nutrients remaining in the soil, a further indirect effect due to changes in the plants themselves, caused by the previous fertilizer applications. These two components cannot, of course, be readily separated, but they are basically very different.

In the second type of experiment the plant-canes received differential treatments and the following ratoons were left untreated. The results from this type of experiment will give an estimate of the residual effects on the crop.

In the third type, differential treatments were applied to ratoons following an original crop previously treated uniformly. The results from these experiments will give an estimate of the direct effect of the fertilizers on the ratoon crop; there will be no residual effects from the applications to plant-canes influencing the results.

2. *Sugar-content.*—The results of experiments in this report are given in terms of the yield of cane, and not in terms of yield of sugar. It is necessary, however, to examine the effect of the various fertilizers on sugar-content, for the increase in yield of cane may be offset in part by a reduction in sugar percentage.

The effects of nitrogen, phosphate, and potash on the percentage sucrose in the cane have been summarized for experiments in British Guiana up to 1940 by Williams and Cameron [2]. The results cover all soil types in the colony and sixteen harvest seasons of plant-canes, and first and second ratoons. With dressings of 2, 4, 6, and 8 cwt. per acre sulphate of ammonia the percentage sucrose fell, on an average by 0·01, 0·10, 0·23, and 0·51 respectively; the last two reductions proved to be statistically significant. Unfortunately the average changes in percentage sucrose with changes in phosphate and potash were not given, but it is stated that in most experiments testing the effect of phosphate there was no significant effect; in some of the remainder the percentage sucrose was increased and in some decreased. Similarly with potash, most experiments showed no significant effect, but on the average there appeared to be a slight tendency towards an improvement in percentage sucrose.

The results of thirty factorial experiments in Queensland have also been examined, and the mean sugar-content in percentage commercial sugar for the various treatments are given in Table 2. The dressings in all experiments were not the same, but in most cases they were very similar and the results were averaged. Where this was not the case the experiments have not been included; for example, one experiment with phosphate used dressings of 400 and 800 lb. superphosphate per acre, so that the means are for twenty-nine experiments only.

The results from these two territories are in general agreement. Nitrogen appears to have an adverse effect on sugar percentage, and the fall with high dressings is appreciable. This is also supported by the results of 289 experiments in the Hawaiian Islands quoted in the above report for British Guiana.

The effect of this reduction in sugar-content on the percentage response is indicated by the following example. The standard response

to nitrogen of 5·4 t. per acre for first ratoons in Queensland [Table 6] is equivalent to a response of 6·8 t. per acre to 380 lb. per acre sulphate of ammonia (20 per cent. N.). If the average yield of first ratoons without nitrogen applications is 20 t. per acre, this then means a response of 34 per cent. Using the percentages 14·99 and 15·33 given in Table 2 to convert the yields into tons of sugar per acre, the yields with and without the nitrogen application are 4·02 and 3·07 t. per acre respectively. The increase in yield of sugar is then approximately 31 per cent. The lower percentage response of sugar is, however, of no great practical importance.

TABLE 2. *Effects of Nitrogen, Phosphate, and Potash on the Mean Percentage of Commercial Sugar from 30 Experiments in Queensland*

| | * *Sulphate of ammonia* | | * *Superphosphate* | | * *Muriate of potash* | |
|---|---|---|---|---|---|---|
| | *Average dressing (lb. per acre)* | *Mean sugar percentage* | *Average dressing (lb. per acre)* | *Mean sugar percentage* | *Average dressing (lb. per acre)* | *Mean sugar percentage* |
| Plant-canes | (30 experiments) | | (27 experiments) | | (29 experiments) | |
| | .. | 15·79 | .. | 15·85 | .. | 15·84 |
| | 180 | 15·75 | 210 | 15·76 | 140 | 15·77 |
| | 360 | 15·57† | 420 | 15·85 | 280 | 15·62 |
| First ratoons | (15 experiments) | | (13 experiments) | | (14 experiments) | |
| | .. | 15·33 | .. | 15·18 | .. | 15·24 |
| | 190 | 15·20 | 190 | 15·34 | 140 | 15·24 |
| | 380 | 14·99 | 380 | 15·34 | 280 | 15·11 |

* The contents of nitrogen, phosphate, and potash in the respective fertilizers were not given.
† The reduction in mean sugar percentage for the highest dressing proved to be just statistically significant at the ·5 per cent. level.

3. *Response curves.*—As different fertilizer applications were used in the experiments it is not possible to obtain mean responses to the various levels of application. It is necessary, therefore, to convert the resulting responses to all different levels of application into responses to some arbitrarily chosen 'standard' dressing. To do this one must establish the relationship between yield and increasing levels of fertilizer application, i.e. the 'response curve'. Knowledge of the response curve is also necessary in order to determine the most economic dressing, i.e. that giving the greatest financial return after allowing for the cost of the fertilizer. The determination of the exact form of the response curve under various conditions would require very extensive experimentation, but the exponential curve introduced by Mitscherlich and used by Crowther and Yates [3] will be sufficient for most practical purposes, and has been adopted here. The relationship between the yield per unit area, $y$, and the dressing per unit area, $x$, is given by the equation

$$y = y_0 + d(1 - 10^{-kx}),$$

where $y_0$ is the yield per unit area obtained in the absence of any dressing of the nutrient under examination, $d$ is the 'limiting' response, i.e. the maximum theoretical response obtained with very large dressings,

and $k$ is a positive constant, which determines the curvature of the response curve. It should be noted that the numerical value of $k$ for a given curve depends on the units in which the dressing is measured.

In experiments where three levels of a given nutrient are tested the value of $k$ may be determined from the ratio of the additional response to the third level of application to the response to the second level of application. If the levels of application are equally spaced, say $a$, $a+b$, $a+2b$, the formula is particularly simple, being

$$k = -\frac{1}{b}\log_{10}\frac{y_2-y_1}{y_1-y_0},$$

where $y_0$, $y_1$, and $y_2$ represent the yields at the three levels of dressing. Since experimental errors will seriously affect the value of the ratio, this formula cannot be used on the results of a single experiment. This, however, is not of great practical importance since it is the mean response curve that is in fact required. The $k$ for this curve can be obtained by using the above formula on the mean yields for the different dressings of any sufficiently extensive series of experiments which all have the same dressings. As mentioned above, there were few experiments with a uniform set of dressings, but it proved possible to form groups of experiments in which the dressings were very similar. The average value of $k$ from such groups of experiments was found for each territory, and the results of these determinations are given in Table 3, the accompanying figures in brackets denoting the number of experiments from which each was derived.

TABLE 3. *Average Values of* $k_N$, $k_P$, *and* $k_K$. (*Dressings of Nitrogen* (N), *Phosphate* ($P_2O_5$), *and Potash* ($K_2O$) *are given in lb. per acre*)

| *Territory* | $k_N$ | $k_P$ | $k_K$ |
|---|---|---|---|
| Jamaica | 0·0096 (73) | 0·0097 (65) | 0·0119 (68) |
| Trinidad | 0·0063 (13) | .. | .. |
| Barbados | 0·0109 (76) | .. | .. |
| Leeward Islands | 0·0054 (170) | .. | 0·0088 (103) |
| British Guiana | 0·0046 (78) | 0·0091 (37) | .. |
| India | 0·0084 (84) | 0·0043 (12) | .. |
| Queensland | 0·0035 (83) | 0·0115 (53) | 0·0101 (58) |
| Miscellaneous | 0·0055 (11) | 0·0072 (7) | 0·0050 (18) |
| Adopted values | 0·006 | 0·010 | 0·010 |
| Values obtained by Crowther and Yates | 0·010 | 0·007 | 0·007 |

Most of the experiments used to determine $k_N$ in British Guiana, Queensland, and Trinidad, were well designed, so that more reliance can be placed on these results. The experiments in Barbados, Jamaica, and India, were older and not well designed, so that the results cannot be regarded as very accurate. Taking into account the probable reliability of the data from the various territories it was considered that a value of 0·006 could be adopted for $k_N$. Only in Jamaica, British Guiana, and

Queensland were the numbers of experiments large enough to give reliable estimates of $k_P$, and they were in close agreement, so that a value of 0·010 was adopted. Apart from the results from eighteen miscellaneous experiments the values for $k_K$ were also very uniform and a value of 0·010 was again adopted. There was little information on pen manure, farmyard manure, and other similar manures, but a few experiments in the West Indies gave 0·03 as an estimate of $k_N$, where the dressings are measured in tons per acre; and this figure was confirmed by about twenty experiments in India.

Crowther and Yates obtained a higher value of 0·010 for $k_N$ when examining arable crops in Great Britain. It may be possible that the lower value for sugar-cane is due to higher rainfall and temperature, but it is a well-known fact that nitrogen stimulates vegetative growth, so that the difference may be due to differences between crops and not to differences in climate. This second suggestion is supported by the value of $k_N$ obtained by Crowther and Yates for sugar-beet tops, which was as low as 0·004.

Having determined the values of $k$, the actual responses obtained in the experiments may be converted into responses to the standard dressings. Dressings of 50 lb. per acre were taken as the standard dressings for nitrogen (N), phosphate ($P_2O_5$), and potash ($K_2O$), and 20 t. per acre was chosen for pen manure and similar organic manures. In the case of nitrogen, phosphate, and pen manure, the average dressings actually used in the experiments were similar to the standard dressings: but in the case of potash they were somewhat higher. The ratio of the response to a dressing $x$ of the nutrient, and the response to the standard dressing $s$, may be found from the Mitscherlich response curve to be

$$R = \frac{1 - 10^{-kx}}{1 - 10^{-ks}}.$$

Taking the response to the standard dressing (i.e. the standard response) as unity, the expected responses to varying dressings relative to the standard responses may be calculated; they are given in Table 4. In

TABLE 4. *Expected Responses to Nitrogen, Phosphate, and Potash relative to the Standard Dressing*

| *Dressing in lb. per acre* | *Relative response* | |
|---|---|---|
| | N | $P_2O_5$ *and* $K_2O$ |
| 10 | 0·259 | 0·301 |
| 20 | 0·484 | 0·540 |
| 30 | 0·680 | 0·730 |
| 40 | 0·851 | 0·880 |
| 50 | 1·000 | 1·000 |
| 60 | 1·130 | 1·095 |
| 70 | 1·243 | 1·171 |
| 80 | 1·341 | 1·231 |
| 90 | 1·427 | 1·278 |
| 100 | 1·501 | 1·316 |

order to convert the response to any given dressing to standard it is necessary merely to divide it by the appropriate relative response; for example, a response of 5·07 t. per acre to an application of 80 lb. per acre of N is equivalent to a standard response of 5·07/1·341 or 3·78 t. per acre.

These standard responses form a basis of comparison between experiments using different dressings, but they are not the responses to the most economic dressing. If it is assumed that the cost of fertilizer application is proportional to the amount applied and also that the value of the yield is proportional to the yield obtained, the expected net gain to the grower may be expressed as

$$G = \frac{vr_s(1-10^{-kx})}{(1-10^{-ks})} - cx,$$

where $v$ is the value per unit of the crop, $r_s$ is the standard response, and $c$ is the cost per lb. of the nutrient. This will be a maximum when the amount of nutrient applied is equal to

$$\frac{1}{k}\log_{10}\left\{\frac{2{\cdot}3026kvr_s}{c(1-10^{-ks})}\right\}.$$

This, then, will be the most economic dressing to use, i.e. the 'optimal' dressing. For the various nutrients examined, this reduces to the following optimal dressings, given in lb. per acre for N, $P_2O_5$, and $K_2O$, and tons per acre for pen manure:

$$\text{N}: \quad 23{\cdot}6+\frac{1}{0{\cdot}006}\log_{10}\frac{vr_s}{50c},$$

$$P_2O_5 \text{ and } K_2O: \quad 22{\cdot}6+\frac{1}{0{\cdot}010}\log_{10}\frac{vr_s}{50c},$$

$$\text{Pen manure}: \quad 8{\cdot}9+\frac{1}{0{\cdot}03}\log_{10}\frac{vr_s}{50c}.$$

Using these formulae the optimal dressings corresponding to a series of ratios of the value of the standard response to the cost per unit of the nutrient are given in Table 5. The net values per acre of the optimal responses from these dressings are then given by the formulae:

$$\text{N}: \quad 2{\cdot}00vr_s-c(72{\cdot}5+x_0),$$

$$P_2O_5 \text{ and } K_2O: \quad 1{\cdot}46vr_s-c(43{\cdot}5+x_0),$$

$$\text{Pen manure}: \quad 1{\cdot}34vr_s-c(14{\cdot}4+x_0),$$

where $x_0$ is the optimal dressing measured in the appropriate units.

To illustrate the use of Table 5, consider the following example: the standard response to phosphate in Queensland is 1·9 t. per acre, and if the grower can sell this at 30*s.* per ton, the gross value of this response is then 57*s.* If superphosphate with content of 18 per cent. $P_2O_5$ costs 20*s.* per cwt., the cost in shillings per lb. $P_2O_5$ will be

$$20/(112\times 0{\cdot}18) = 0{\cdot}992.$$

Then the ratio $R = vr_s/c = 57/0{\cdot}992 = 57{\cdot}5$. Using linear interpolation in Table 5, the optimal dressing will be 27·8 lb. per acre $P_2O_5$, or about

1·4 cwt. per acre superphosphate. (The correct value, obtained by substitution in the above formula, is 28·6 lb.) In practice no great accuracy is required, since dressings considerably different from the theoretical optimum make little difference to the net return. For example, with the above values and costs, the theoretical expected net gains for dressings of 20, 25, 28·6, 30, and 35 lb. per acre $P_2O_5$ are 10·9, 11·7, 11·8, 11·8, 10·6 shillings per acre respectively. In other words a dressing lower by about 30 per cent. than the optimum will produce a net gain only about 8 per cent. lower than that obtained for the optimum.

TABLE 5. *Optimal Dressings (given in lb. per acre) for Various Values of the Ratio* $vr_s/c$

| $vr_s/c$ | N | $P_2O_5$ *and* $K_2O$ |
|---|---|---|
| 50 | 24 | 23 |
| 75 | 53 | 40 |
| 100 | 74 | 53 |
| 150 | 103 | 70 |
| 200 | 124 | 83 |
| 300 | 153 | 100 |
| 400 | 174 | 113 |
| 500 | 190 | 123 |

4. *Average standard responses.*—The responses of plant-canes and first and second ratoons were converted to responses to the standard dressings of the three nutrients, and the average values of these standard responses for each territory are given in Table 6. The experiments were subdivided into those that received no basal dressings and those that received basal dressings of pen manure or green manure in the first year. The ratoon data given in the table were all from experiments in which the same or very similar differential treatments were applied to the ratoons and the preceding crops. The figures in brackets denote the number of experiments used to derive the accompanying average standard responses.

4A. *Nitrogen.*—Table 6 shows a consistent difference between the responses of plant-canes and ratoons to nitrogen; the difference, however, is more clearly shown in Table 7, where the standard responses have been averaged over all experiments. This table, however, does not provide a very accurate estimate of the magnitude of the differences in response between the two crops, because the two sets of results were not wholly derived from the same experiments. In Jamaica, for example, experiments in the more responsive parishes contribute 57 per cent. of the plant-cane data as opposed to only 37 per cent. of the first ratoon data. In order to provide more strictly comparable results it is necessary to calculate means from those experiments which provide data for both plant-canes and ratoons. The results of 169 experiments, on plant-canes and the succeeding first ratoons, together with the results of sixty-seven experiments on first ratoons and the following second ratoons, are given in Table 8. The standard responses of first and second ratoons are approximately equal and roughly double that of plant-canes.

TABLE 6. *Average Responses of Sugar-cane (in tons per acre) to the Standard Fertilizer Dressings*

| | *Plant-canes* | | | *First ratoons* | | | *Other ratoons* | | |
|---|---|---|---|---|---|---|---|---|---|
| | *O* | *P.M.* | *G.M.* | *O* | *P.M.* | *G.M.* | *O* | *P.M.* | *G.M.* |
| N | | | | | | | | | |
| Jamaica | 2·2 (70) | −0·5 (2) | .. | 1·4 (27) | .. | .. | 3·5 (20) | .. | .. |
| Trinidad | 1·8 (2) | 2·8 (50) | .. | 5·4 (14) | 3·1 (2) | .. | 5·7 (2) | 6·6 (2) | .. |
| Barbados | 2·6 (28) | 1·3 (35) | .. | 5·1 (9) | 5·4 (6) | .. | .. | 4·4 (7) | .. |
| Leeward Islands | 2·2 (23) | .. | .. | 5·0 (9) | 4·3 (20) | .. | .. | .. | .. |
| British Guiana | 5·0 (43) | .. | .. | 6·7 (35) | .. | .. | 4·3 (26) | .. | .. |
| South Africa | 0·9 (25) | .. | .. | 2·6 (2) | .. | .. | 3·5 (6) | .. | .. |
| Mauritius | 1·9 (19) | 1·3 (26) | .. | 4·0 (16) | 1·1 (10) | .. | 3·6 (20) | 0·8 (8) | .. |
| India | 5·0 (86) | 3·5 (40) | 3·2 (34) | .. | .. | .. | .. | .. | .. |
| Queensland | 2·8 (92) | .. | 1·4 (32) | 5·4 (57) | .. | 5·5 (16) | 7·2 (23) | .. | 7·8 (9) |
| $P_2O_5$ | | | | | | | | | |
| Jamaica | 0·1 (56) | .. | .. | −0·4 (23) | .. | .. | 0·1 (15) | .. | .. |
| Trinidad | .. | 4·3 (1) | .. | .. | .. | .. | 0·3 (1) | .. | .. |
| Barbados | 0·3 (21) | 0·1 (51) | .. | −1·6 (5) | 0·7 (11) | .. | .. | −1·2 (2) | .. |
| Leeward Islands | 0·2 (23) | −0·2 (26) | .. | 0·3 (7) | −0·4 (16) | .. | .. | .. | .. |
| British Guiana | 2·4 (37) | .. | .. | 1·6 (21) | .. | .. | 2·1 (27) | .. | .. |
| South Africa | 4·4 (27) | .. | .. | 4·2 (1) | .. | .. | 3·0 (3) | .. | .. |
| Mauritius | 5·4 (23) | 0·7 (18) | .. | 7·0 (17) | 1·2 (8) | .. | 4·7 (24) | 0·2 (8) | .. |
| India | 0·8 (39) | 1·4 (25) | 2·4 (35) | .. | .. | .. | .. | .. | .. |
| Queensland | 2·3 (69) | .. | 1·8 (30) | 1·6 (50) | .. | 0·8 (15) | 2·2 (23) | .. | 1·5 (9) |
| $K_2O$ | | | | | | | | | .. |
| Jamaica | 1·6 (62) | .. | .. | 1·8 (27) | .. | .. | 1·1 (18) | .. | .. |
| Trinidad | 2·4 (2) | 2·6 (7) | .. | .. | 2·4 (1) | .. | 1·4 (1) | .. | .. |
| Barbados | 0·7 (23) | 0·8 (46) | .. | 3·8 (5) | 0·7 (10) | .. | .. | 1·6 (7) | .. |
| Leeward Islands | 2·3 (27) | 0·8 (27) | .. | 1·0 (9) | 0·7 (13) | .. | 0·3 (1) | .. | .. |
| British Guiana | 1·1 (16) | .. | .. | 0·9 (9) | .. | .. | 0·5 (15) | .. | .. |
| South Africa | 2·2 (23) | .. | .. | 4·6 (4) | .. | .. | 1·6 (3) | .. | .. |
| Mauritius | 3·1 (15) | 1·0 (13) | .. | 3·7 (14) | 0·6 (7) | .. | 4·3 (20) | −0·2 (6) | .. |
| India | −0·9 (19) | 1·0 (14) | 2·4 (7) | .. | .. | .. | .. | .. | .. |
| Queensland | 1·7 (76) | .. | 1·6 (29) | 1·6 (54) | .. | 1·4 (16) | 3·0 (27) | .. | 2·4 (10) |

*P.M.* = Pen manure basal on plant-canes. *G.M.* = Green manure basal on plant-canes. *O* = Neither.

TABLE 7. *Mean Standard Responses (in tons per acre)*

| Territory | Nitrogen | | Phosphate | Potash |
|---|---|---|---|---|
| | Plant-canes | Ratoons | | |
| Jamaica . . . | 2·1 (72) | 2·3 (47) | 0·0 (94) | 1·6 (107) |
| Trinidad . . . | 2·8 (52) | 5·3 (20) | 2·3 (2) | 2·4 (11) |
| Barbados . . . | 1·9 (63) | 5·0 (22) | 0·1 (90) | 1·0 (71) |
| Leeward Islands . . | 2·2 (23) | 4·5 (29) | 0·1 (72) | 1·3 (78) |
| British Guiana . . | 5·0 (43) | 5·7 (61) | 2·1 (85) | 0·8 (40) |
| South Africa . . | 0·9 (25) | 3·3 (8) | 4·3 (31) | 2·5 (30) |
| Mauritius . . . | 1·6 (45) | 2·8 (54) | 3·9 (98) | 2·7 (75) |
| India . . . . | 4·2 (160) | .. | 1·5 (99) | 0·3 (40) |
| Queensland . . . | 2·4 (124) | 6·0 (96) | 1·9 (187) | 1·8 (212) |

TABLE 8. *Standard Nitrogen Responses (in tons per acre) of Plant-canes and the Following First Ratoons, and of First Ratoons and the Following Second Ratoons; all Crops receiving the Same Treatments*

| Territory | Number of expts. | Response of | Number of expts. | Response of | |
|---|---|---|---|---|---|
| | | Plant-canes | First ratoons | First ratoons | Second ratoons |
| Jamaica . . . | 21 | 1·3 | 1·9 | 5 | 1·2 | 2·6 |
| Trinidad . . . | 4 | 0·7 | 3·0 | 2 | 5·8 | 6·7 |
| Barbados . . . | 12 | 2·8 | 5·5 | 3 | 7·0 | 6·3 |
| Leeward Islands . . | 27 | 1·1 | 4·1 | .. | .. | .. |
| British Guiana . . | 23 | 4·4 | 6·4 | 16 | 5·7 | 3·9 |
| South Africa . . | 2 | 0·5 | 2·6 | .. | .. | .. |
| Mauritius . . . | 25 | 1·9 | 2·7 | 21 | 3·4 | 2·8 |
| Queensland . . . | 55 | 2·2 | 5·2 | 20 | 5·6 | 7·0 |
| Total and weighted means . . . | 169 | 2·1 | 4·4 | 67 | 4·7 | 4·6 |

Only eleven of the experiments abstracted tested the residual effect of nitrogen and these gave a mean residual of —0·2 t. per acre, but seven of these were in South Africa where even the direct response was poor.

Experiments in the Leeward Islands and in British Guiana were conducted on first ratoons following uniformly treated plant-canes, and there was a tendency for the nitrogen responses in these experiments to be less than those of first ratoons receiving the same differential treatments as the preceding plant-canes. In this case a comparison of two sets of responses from experiments on the same sites cannot be made, but a comparison of the experiments carried out on the same estates give a mean standard response of first ratoons of 5·7 t. when the same treatments were applied to both crops, and a response of 4·2 t. when the plant-canes were uniformly treated. (These means are calculated so as to eliminate differences between estates from the comparison between them.)

The differences in the responses obtained in the territories considered are due to various factors, but the available data on the various climatic

and geographical factors are neither sufficiently accurate nor abundant to allow any final conclusions to be made. On general grounds it seems likely that the variation in response may be due to differences in rainfall, for in regions where this is high, water is not likely to be a limiting factor in plant-growth, and in addition the nitrogen-content of the soil is liable to become low through leaching. Results from the various countries suggest that this is the case; contrast, for example, the responses in the Leeward Islands, given in Table 7 with the higher ones obtained in British Guiana. In the former the rainfall is comparatively low—in the region of 40 to 60 in.—whereas in the latter the rainfall is normally about 90 in. The responses are also low in the South African cane-belt where the rainfall is about 40 in., and responses in the Lower Burdekin Delta of Queensland, where irrigation is practised, are higher than those in the remainder of the cane-growing areas of Queensland.

There are, of course, some exceptions. In the black-soil region of Barbados fifty-two experiments on plant-canes and four experiments on ratoons gave average responses of 2·9 and 5·7 t. per acre respectively. Results on red soils in that territory gave average standard responses of 2·3 and 5·0 t. per acre respectively, derived from seventeen and eleven experiments. The rainfall in the red-soil region is higher; these results, then, do not follow the usual pattern of behaviour associated with rainfall. Soil analyses show that, in spite of the higher rainfall, the nitrogen-content of the red soils is about 0·26 per cent., whereas that of the black soils is only about 0·15 per cent.

Many experiments provided a comparison between sulphate of ammonia and nitrate of soda. These were applied on an equal nitrogen basis in 254 experiments. The average standard response to sulphate of ammonia in these experiments was 3·3 t. per acre and that to nitrate of soda was 3·0 t. per acre. It may therefore be concluded that there is little difference in effectiveness between the two forms of nitrogen. Other forms of inorganic nitrogenous fertilizer were also compared with these two types, but the numbers of experiments were very low. Organic fertilizer in the form of dried blood appears to produce a standard response of only 70 per cent. of that of sulphate of ammonia, but it may well have an appreciable residual effect. About forty Indian experiments indicated that better results could be obtained from the inorganic fertilizer than from organics in the form of groundnut, castor, toria, and mohua cake, on an equal nitrogen basis.

4B. *Phosphate.*—In general, the responses to phosphate seem to be more variable than those to nitrogen. The results in Table 6 do not show any obvious difference in the responses of plant-canes and ratoons, but the question cannot be decided without further investigation into the residual effect.

Apart from Jamaica, Barbados, and Leeward Islands, where the direct effects of phosphate were small, South Africa was the only territory in which there were experiments testing the residual effect of phosphate. The data, however, were very scanty; a series of seven experiments gave a standard response of 2·9 t. per acre with plant-canes and a first year residual on ratoons of 2·2 t. per acre. A further series of only three

experiments gave a standard response of 7·4 t. per acre with plant-canes, and first- and second-year residual responses of 4·2 and 3·1 t. per acre respectively on ratoons. These results are indicative of a substantial residual effect. On the other hand, Table 9 shows that in experiments where phosphate was applied to both plant-canes and ratoons the responses are very similar in both crops. Further experimental investigation is obviously necessary before it is decided whether it would be sound fertilizer practice to give lower dressings of phosphate to ratoons.

TABLE 9. *Standard Phosphate Responses (in tons per acre) of Plant-canes and the Following First Ratoons; both Crops receiving the Same Treatments*

| *Territory* | *Number of expts.* | *Response of* | |
|---|---|---|---|
| | | *Plant-canes* | *First ratoons* |
| British Guiana . . . | 19 | 2·0 | 1·7 |
| South Africa . . . | 1 | 4·8 | 4·2 |
| Mauritius . . . . | 25 | 5·2 | 5·0 |
| Queensland . . . | 43 | 2·0 | 1·9 |
| Total and weighted means . | 88 | 2·9 | 2·7 |

South Africa is exceptional in the relatively high responses obtained for phosphate and the relatively low responses to nitrogen. Mauritius would appear to be similar to South Africa in this respect, but the majority of the experiments, mainly those without a basal dressing of organic manure, were conducted at the Reduit Experimental Station, which seems to be particularly responsive to phosphate. The remaining experiments were conducted in six different districts and gave a very small average standard response of 0·4 t. per acre in contrast to the overall figure of 3·9 t. per acre. It is probable that the smaller response is more representative of the island as a whole.

The results given in Table 6 for experiments with and without basic dressings of organic manures are not, of course, strictly comparable. The results from India, for example, would appear to indicate a positive interaction; but a legitimate comparison of responses may be obtained from only seven experiments in the Punjab. In these experiments the average standard response with no basal organic was 2·2 t. per acre, with a basal of pen manure the mean response was 0·1 t. per acre, and with a green manure it was 0·6 t. per acre.

As in the case of nitrogen, rainfall appears to have an appreciable effect on the response to phosphate. In Queensland, for example, there is a reduction in response from north to south coinciding with a reduction in the annual rainfall. Similarly, the rainfall and the phosphate response are higher in British Guiana than in Barbados and the Leeward Islands. Crowther and Yates found that the phosphate response of arable crops in Great Britain also increased with increasing rainfall. The responses to phosphate in countries where the available phosphate (as indicated by soil analysis) is generally low, as in British Guiana and South Africa for example, are higher than those in countries where the soil is not deficient

in phosphate, as in Jamaica and Barbados. Low values of available phosphate tend to be associated with high rainfall.

In most experiments phosphate was applied in the form of superphosphate, but several experiments compared other forms of phosphatic fertilizer with superphosphate. Curaçao rock phosphate was tested in British Guiana and it proved to be less efficient than superphosphate on an equal-phosphate basis. Rock phosphates used in South African experiments produced results comparable with superphosphate. One of the experiments tested Egyptian, Morocco, Christmas Island and Florida rock phosphate, but the remainder tested only Egyptian. Guano was tested in Mauritius and proved to be as efficient as superphosphate. Most experiments with basic slag were carried out in the West Indies where the response to all forms of phosphate appears to be negligible, but in British Guiana experiments with basic slag indicated that it was as effective as superphosphate on an equal-phosphate basis.

4c. *Potash.*—The responses of cane to potash seem to be less variable than those to phosphate. The results in Table 6 do not indicate any large difference between plant-canes and ratoons, but again the question of residual response must be considered. As in the case of phosphate there are few experiments giving an estimate of the residual effect of potash, and only six experiments in South Africa were abstracted. These gave an average standard response of 3·4 t. per acre in the year of application, and a mean residual response of 1·0 t. per acre. This result indicates the presence of some residual effect. The results of 125 experiments in which potash was applied to both the plant-canes and the ratoons are given in Table 10. On the average there is a slightly greater response in the ratoons. A similar comparison between first and second ratoons based on thirty-six experiments gave an average standard response of 2·3 t. per acre with first ratoons and an average of 2·6 t. per acre with second ratoons.

TABLE 10. *Standard Potash Response (in tons per acre) of Plant-canes and the Following First Ratoons; both Crops receiving the Same Treatments*

| *Territory* | *Number of expts.* | *Response of* | |
|---|---|---|---|
| | | *Plant-canes* | *First ratoons* |
| Jamaica . . . . | 16 | 1·2 | 1·7 |
| Barbados . . . . | 9 | 0·9 | 1·4 |
| Leeward Islands . . | 17 | 1·5 | 1·1 |
| British Guiana . . . | 8 | 0·8 | 1·0 |
| South Africa . . . | 4 | 2·7 | 4·5 |
| Mauritius . . . . | 21 | 2·5 | 2·7 |
| Queensland . . . | 50 | 1·2 | 1·5 |
| Total and weighted means . | 125 | 1·4 | 1·7 |

The responses given in Table 6 for experiments with and without basal dressings of organic manures are not strictly comparable. In Mauritius, for example, experiments with a basal dressing were scattered throughout the territory, whilst those without were mainly at the Reduit

Experimental Station where the soil appears to be particularly responsive to potash. The small number of experiments in India were scattered widely so that no reliable comparisons can be made in this case.

The effect of rainfall on the response to potash is not as marked as its effect on the responses to the two other nutrients, though there is an indication that the response increases with heavier rainfall. The volcanic and alluvial soils of Queensland, for example, can be divided into southern or central districts and the northern district, and the heavier rainfall in the north coincides with a greater response in that area. The volcanic soils of this territory, and, to a lesser extent the schist soils, have a low potash-content, and average standard responses obtained in fifty-seven and twenty-five experiments respectively were 3·1 and 2·4 t. per acre. The alluvial and sandy soils usually have a greater percentage potash, and responses obtained in seventy-seven and forty-five experiments respectively were 1·2 and 1·1 t. per acre. The soils in British Guiana are also generally well supplied, whilst those of South Africa are generally deficient; this difference is reflected in the difference between the responses from the two territories.

4D. *Interactions.*—Most of the relevant data on the interactions between nitrogen, phosphate, and potash were from old and not too reliable experiments, the majority of which were in the Leeward Islands. Reports of quite a number of $3^3$ experiments in Queensland and British Guiana did not include sufficient data to determine the interactions. The results of about 130 experiments in each case were available for forming estimates of the three interactions. The average standard responses from these experiments are given in Table 11. There seems to be little interaction between nitrogen and either phosphate or potash, but there is some indication of a positive interaction between phosphate and potash.

TABLE 11. *The Two-factor Interactions. Standard Responses of Cane (in tons per acre) to* N, P, *and* K, *in the Presence and Absence of One Other Factor*

| *Each component separately* | | | *Both components together* |
|---|---|---|---|
| N | P | Sum | N+P |
| 3·0 | 1·2 | 4·2 | 4·3 |
| N | K | Sum | N+K |
| 3·1 | 1·4 | 4·5 | 4·4 |
| P | K | Sum | P+K |
| 0·4 | 1·3 | 1·7 | 2·2 |

5. *Organic manures*

5A. *Pen manure.*—The average responses to the standard dressing of pen manure in the various territories are given in Table 12. Apart from India and the Leeward Islands the number of experiments in each territory is small, but the results are consistent. The information on the residual effect of pen manure is very limited, but the seven experiments

continued on first ratoons in the Leeward Islands, and the four continued on second ratoons in Trinidad, suggest that the residual effect is quite appreciable.

TABLE 12. *Direct Responses (in tons per acre) of Plant-canes and Residual Responses of Ratoons to 20 tons per acre of Pen Manure*

| *Territory* | *Response of* | | |
|---|---|---|---|
| | *Plant-canes* | *First ratoons* | *Second ratoons* |
| Trinidad . . . | 6·6 (2) | 2·9 (3) | 2·1 (4) |
| Barbados . . . | 3·1 (7) | .. | .. |
| Leeward Islands . . | 4·1 (22) | 3·4 (7) | .. |
| British Guiana . . | 7·7 (2) | .. | .. |
| Mauritius . . . | 4·5 (3) | .. | .. |
| India . . . . | 4·8 (50) | .. | .. |

As pen manure is a source of phosphate and potash, and, to a lesser extent, nitrogen, it is natural to expect a negative interaction between it and the three inorganic fertilizers. Few experiments were abstracted in which it was possible to estimate the responses of nitrogen, phosphate, and potash, in the presence and absence of pen manure. It was decided therefore to form a comparison of the responses to the three inorganics from different experiments on the same estate, separating them into those which received an overall basal dressing of pen manure and those which did not. The mean responses for the various estates were determined for four of the territories, and the averages of these are given in Table 13. The reduction in the response to the standard dressing of nitrogen caused by a basal dressing of pen manure is about 20 per cent., and the average reduction in the standard responses to both phosphate and potash is 50 per cent. These results are in general agreement with those obtained by Crowther and Yates for root crops in Great Britain; the percentage reduction for phosphate and potash was the same, but that for nitrogen was somewhat lower, in the region of 10 per cent.

TABLE 13. *Standard Response (in tons per acre) to Nitrogen, Phosphate, and Potash, with and without a Basal Dressing of Pen Manure*

| | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| No basal . . . . | 2·3 | 1·2 | 1·4 |
| With pen manure . . . | 1·8 | 0·6 | 0·7 |

5B. *Green manure.*—Only eighteen experiments (seventeen in India and one in South Africa) were abstracted which measured the direct effect of a green manure on cane-yield; all were conducted on plant-canes and tested the effect of ploughing in a legume grown *in situ*. A response of 2·6 t. per acre was obtained in the South African experiment and an average response of 5·4 t. per acre in India. These experiments indicate that the use of legumes in this manner will produce good results. No definite evidence on the residual effect of green manure was obtained, but results indicate that it is small.

TABLE 14. *Standard Responses (in tons per acre) to Nitrogen, Phosphate, and Potash with and without a Green Manure*

| | N | $P_2O_5$ | $K_2O$ |
|---|---|---|---|
| No basal . . . . | 2·6 | 1·9 | 1·6 |
| With green manure . . | 1·4 | 1·7 | 1·4 |

There are also no experiments to determine the interaction between green manure and the three inorganic fertilizers, but, as with pen manure, it is possible to compare experiments with and without a previous green-manure crop on the same estates. A total of 123 experiments (forty-seven with and seventy-six without previous green manure) were available and the average standard responses are given in Table 14. The responses to phosphate and potash are reduced by only a small amount, but there is a strong negative interaction with nitrogen. It is noteworthy that in Queensland a green manure is generally considered to supply sufficient nitrogen for the requirements of the plant-canes; and no other nitrogenous fertilizer is applied to the crop; dressings are, however, given to the succeeding ratoon crops.

5c. *Molasses.* The main value of molasses as a fertilizer lies in its relatively high potash-content of about 3 per cent. The experiments testing its effect on cane-yield were few, and are summarized in Tables 15 and 16. Seven of the experiments in Mauritius were continued on

TABLE 15. *Responses (in tons per acre) to Different Dressings of Molasses, and Standard Responses assuming a 3 per cent. Potash-content*

| *Territory* | *Number of expts.* | *Dressing* | *Response* | *Standard response* |
|---|---|---|---|---|
| Leeward Islands . | 6 | 200 gals. (no basal) | 3·0 | 2·4 |
| | 13 | (with pen manure) | 0·8 | 0·6 |
| Mauritius . . | 11 | 20 tierces (about 700 gals.) | 3·2 | 2·2 |
| India (Shahjuhampar) | 1 | 90 maunds (about 500 gals.) | 1·5 | 1·0 |
| | 1 | 180 ,, ( ,, 1,000 ,, ) | 3·2 | 2·2 |
| | 1 | 270 ,, ( ,, 1,500 ,, ) | 4·7 | 3·2 |

first ratoons and an average residual response of 0·5 t. per acre was obtained. This low response should not be taken as indicative of the general lack of a lasting effect of the molasses, for, in addition to the low number of experiments involved, three of these, when continued further on second ratoons, produced an average second-year residual of almost 2 t. per acre. Assuming that the value of molasses lies only in its 3 per cent. potash-content, the standard responses were determined for the experiments given in Table 14. Those obtained for the experiments in the Leeward Islands are in general agreement with the average standard responses to potash for that territory given in Table 6; that for Mauritius is somewhat lower, and those for India somewhat higher than the corresponding responses in Table 6.

TABLE 16. *Responses (in tons per acre of Plant-canes and Ratoons) to 10 tons per acre Molasses (M) or its equivalent in Inorganics (A) applied to the Plant-canes from 3 Experiments in Queensland*

| *District* | *Plant-canes* | | *First ratoons* | | *Second ratoons* | |
|---|---|---|---|---|---|---|
| | *M* | *A* | *M* | *A* | *M* | *A* |
| Northern . . | 12·8 | 9·9 | 11·0 | 12·5 | 5·1 | 3·7 |
| Central . . | 6·0 | 7·9 | 3·8 | 8·7 | .. | .. |
| Southern . . | 14·4 | .. | 17·5 | .. | .. | .. |

Two of the three experiments in Queensland given in Table 16 actually compared the effect of molasses with that of its equivalent in plant-nutrients applied as sulphate of ammonia, superphosphate, and sulphate of potash. The results do not suggest any great difference between molasses and its equivalent in inorganic fertilizers. Differences in response in the three experiments are in general agreement with differences obtained in responses to potash; the potash-deficient soils of the southern district have given the best response, and the alluvial soils of the north, where rainfall is higher, have produced better responses than the similar soil type in the central district.

6. *Soil acidity and liming.*—There were few experiments testing the effect of lime, and it is not possible to draw any definite conclusions, but the results of abstracted experiments are given in Table 17. The soils in Trinidad, British Guiana, and Mauritius are predominantly acid, whilst the soils of Barbados and Antigua, for example, usually have a sufficiency of calcium carbonate and are not very acid. These differences

TABLE 17. *Responses (in tons per acre) of Plant-canes caused by Liming*

| *Territory* | *Number of expts.* | *Form of lime* (where given)* | *Average dressing (cwt./acre)* | *Response* |
|---|---|---|---|---|
| Jamaica . . . . | 28 | ? | 10 | 4·4 |
| Trinidad . . . . | 5 | *g* | 150 | 7·4 |
| Barbados . . . . | 3 | *s* | 10 | 0·7 |
| St. Kitt's . . . . | 5 | *s, b, g* | 40 | 1·6 |
| Antigua . . . . | 7 | ? | 2 | 0·7 |
| Antigua . . . . | 1 | *g* | 800 | 1·7 |
| British Guiana . . . | 18 | *s, g* | 60 | 3·0 |
| South Africa . . . | 1 | *b* | 70 | 0·1 |
| Mauritius . . . | 6 | ? | 10 | 1·8 |
| India . . . . | 5 | ? | 10 | 0·6 |

* *s* = slaked lime. *b* = burnt lime. *g* = ground limestone. ? = form of lime not stated.

in soil type are reflected in the responses given in the table. The soils of Jamaica, however, are seldom acid but are nevertheless usually deficient in calcium carbonate, due to large amounts of sodium salts, and therefore show good responses to lime. A few experiments were continued on ratoons to estimate the residual effect of liming. The results in Jamaica,

Trinidad, and Mauritius were good, but the residual responses in British Guiana were low.

*Acknowledgements.*—We express our thanks to Dr. F. Yates for his advice and criticism, and also to Mr. G. E. Hodnett for his help during the preparation of this paper.

*Summary*

The paper contains a summary of the results of about 1,500 fertilizer experiments on sugar-cane conducted in various territories of the British Commonwealth between about 1900 and 1943. Constants for the response curves for nitrogen, phosphate, and potash were determined and were found to be similar to those given by Crowther and Yates. The means of the standardized responses of plant-canes and ratoons to these plant-nutrients are presented for the various territories. As might be expected, there is considerable variation in these responses from territory to territory, and for different soil types and climatic conditions within territories. There is little evidence of interactions between the different nutrients. Experiments comparing nitrate of soda and sulphate of ammonia showed little difference between the two forms. Experiments contrasting superphosphate with rock phosphate gave variable results probably associated with the form of rock phosphate used.

In most of the experiments the dressings were repeated on each crop. It was found that in these circumstances the response of ratoons to nitrogen was about double that of plant-canes, but there was little difference in the responses to phosphate and potash.

The results of some experiments with pen manure, green manure, molasses, and lime were also abstracted and examined.

REFERENCES

1. R. F. Innes and T. Chinloy, The Effects of Fertilizers on Sugar-cane. I. Potash. Read at a meeting of the B.W.I. Sugar Technologists in British Guiana, 1951.
2. C. H. B. Williams and C. Cameron, British Guiana Dept. of Agric., 1940, Sugar Bulletin No. 9, 49.
3. E. M. Crowther and F. Yates, Empire J. Expt. Agric., 1941, **9**, 77–97.

(*Received September 2, 1952*)

# THE PALATABILITY OF HERBAGE ON UNDEVELOPED GRASSLANDS IN WEST-CENTRAL WALES

W. E. J. MILTON

(*Welsh Plant-breeding Station, Aberystwyth*)

THE whole of east Cardiganshire is occupied by hills and moorlands extending into south-west Montgomeryshire, west Radnorshire, and the north-west corner of Breconshire. This block of upland country consists of the Plynlymon range of hills which extend for 32 miles in a north to south direction, and the width of the area can be taken arbitrarily as 20 miles. The soil is derived from the hard shales and grits of the Ordovician and Silurian series [1] which give rise to a light loam soil—a soil type, though naturally well drained, which is frequently overlaid by boulder clay derived from glacial drift. When this occurs drainage is greatly impeded, and on the hills peat formation is usually the result, but excessive moisture is more usually caused by seepage of water from still higher ground. The climate of the Plynlymon area is one of mild temperature and high rainfall, being typical of upland country exposed to prevailing south-westerly winds. A 40- to 50-in. rainfall on the coastal hills in Cardiganshire rises rapidly to 70 and 80 in. as the land surface approaches the 2,000-ft. contour. The dry east winds that usually prevail during March, April, and early May, however, enable the soils to become drained of surplus moisture with the exception of catchment areas of large or small extent.

An investigation of the plant associations in their relation to soil type has been carried out on these hills with special reference to the species of grasses and herbs which the grazing animal prefers. These palatability data were considered in relation to the amount offering to the animals of each particular species in the association under observation, the results being recorded as scores for relative abundance and for amount eaten. Such factors as discoloration of the leafage and 'burn' or withering of leafage as influencing grazing were noted, and these data have been given in the seasonal results. The findings of this investigation for the years 1931 and 1932 appeared, together with palatability data for all classes of grazing land, both lowland and upland, in 1933 [2]. Observations have continued up to 1951 and the main results are recorded in Tables 1–4 in this paper.

Data gathered over several years on the relative amount grazed of a species in relation to the amount offering, i.e. its palatability, are necessary for obtaining a true picture of their agricultural significance. These particulars are given as average results in the tables. Scores were given on a scale of 0–10 (10 = most grazed) for the relative amount of a species eaten in regard to its frequency among the remainder of the herbage [2]. The grazing animals were chiefly the native breed of sheep, but there were also cattle in numerous instances and also some ponies. Commencing in winter before any new growth has been made, the scores in

[Empire Journ. of Exper. Agric., Vol. 21, No. 82. 1953.]

Table 1 show that every species listed is grazed to some extent, but that there are marked differences in the amounts eaten among the species. Where there was discoloured or withered leafage present (winter burn), as in the case of *Luzula maxima*, *Juncus communis*, and *Galluna vulgaris*,

TABLE 1. *The Relative Palatability of Species on Open Hill Grazings based on Scores of 0–10 (10 = most grazed)*

WINTER PERIOD

| *Species* | *Average scores* | *Species* | *Average scores* |
|---|---|---|---|
| *Festuca ovina*, L. | 8 | *Potentilla erecta*, H. | 3 |
| Agrostis spp. | 10 | *Plantago lanceolata*, L. | 5 |
| *Triodia decumbens*, B. | 10 | *Juncus squarrosus*, L. | 10 |
| *Luzula campestris*, D.C. | 9 | *J. communis*, M. (g) | 6 |
| *L. maxima*, D.C. (g) | 1 | ,, ,, (b) | 0 |
| ,, ,, (b) | 0 | *Vaccinium Myrtillus*, L. | 4 |
| Carex spp. | 9 | *Calluna vulgaris*, H. (g) | 2 |
| *Galium saxatile*, L. | 3 | ,, ,, (b) | 0 |

(g) = green leafage, (b) = burnt leafage

only the green leaves were picked out, the burnt being avoided. The most palatable species during the *winter period* were Agrostis (bent), Triodia (heath-grass), and *Juncus squarrosus* (heath-rush), but *Festuca ovina* (sheep's fescue), *Luzula campestris* (field woodrush), and the Carex species (sedges) were almost as palatable (Table 1).

These species of Carex found among the Plynlymon hills are chiefly *C. echinata* (Murr.), *C. canescens* L., *C. Goodenovii* (Gay), *C. pilulifera* L., and *C. praecox* (Jacq.). Salter [3] records numerous other species of Carex that are associated with the Cardiganshire uplands and moist habitats in addition to those enumerated.

The hard grazing of heath-rush during the winter was very marked. Among the larger plants which usually had their outer leaves winter burnt, only the green plant-centres were eaten, but where small green Juncus plants occurred among the other herbage it was rare to find such a plant that had not been well grazed. It was observed that whereas sheep nibble the green tips of heather in winter, cattle will on occasion graze continually for some hours on pure heather leafage.

The relative palatability of the species in the *early spring* months is given in Table 2. It is governed mainly by the amount of green material remaining over from the preceding winter. This varies considerably from year to year according to the climatic conditions. Fescue, bent, and Nardus were the chief grasses providing keep on the various plant associations, and it will be seen that their green material was eaten to varying degrees. It was observed that the green centres of the smaller Nardus plants spaced among other species of an association were the chief plants that were grazed; a dense mass of Nardus growing in a pure colony was avoided during the spring period owing to its general 'burn'. Table 2 shows that heath-grass, Anthoxanthum (sweet vernal), Holcus (Yorkshire fog), and heath-rush were highly palatable species, as were also the various species of Carex. Cattle were seen to pick out what green

TABLE 2. *The Relative Palatability of Species on Open Hill Grazings based on Scores of 0–10 (10 = most grazed)*

SPRING PERIOD

| *Species* | *Average scores* | *Species* | *Average scores* |
|---|---|---|---|
| *Festuca ovina*, L. (g) | 7 | *Holcus lanatus*, L. | 10 |
| ,, ,, (b) | 0 | *Luzula campestris*, D.C. | 3 |
| Agrostis spp. (g) | 6 | Carex spp. | 8 |
| ,, ,, (b) | 0 | *Juncus squarrosus*, L. | 10 |
| *Nardus stricta*, L. (g) | 3 | ,, *articulatus*, L. (g) | 2 |
| ,, ,, (b) | 0 | ,, ,, (b) | 0 |
| *Triodia decumbens*, B. | 10 | *Calluna vulgaris*, H. | 2 |
| *Anthoxanthum odoratum*, L. | 9 | *Erica Tetralix*, L. | 2 |

(g) = green leafage, (b) = burnt leafage.

leaves were offering among the colonies of *Juncus articulatus* (jointed rush), although the quantity was invariably small in proportion to the quantity of withered material of this species present during this period. Both Calluna (heather) and *Erica Tetralix* (cross-leaved heath) were eaten during the spring months, but to a small degree compared with the majority of the other species in the table.

In *summer* the herbage is green throughout, and the relative palatability of the species (Table 3) is therefore uninfluenced by the presence of discoloured or withered leafage among its herbage; sheep grazing as

TABLE 3. *The Relative Palatability of Species on Open Hill Grazings based on Scores of 0–10 (10 = most grazed)*

SUMMER PERIOD

| *Species* | *Average scores* | *Species* | *Average scores* |
|---|---|---|---|
| *Festuca ovina*, L. | 5 | *Plantago lanceolata*, L. | 10 |
| Agrostis spp. | 9 | *Achillea Millefolium*, L. | 6 |
| *Nardus stricta*, L. | 3 | *Juncus squarrosus*, L. | 6 |
| *Molinia caerulea*, M. | 10 | *Scirpus caespitosus*, L. | 10 |
| *Triodia decumbens*, B. | 6 | *Vaccinium Myrtillus*, L. | 1 |
| *Anthoxanthum odoratum*, L. | 9 | *Calluna vulgaris*, H. | 1 |
| *Luzula campestris*, D.C. | 10 | *Erica Tetralix*, L. | 1 |
| Carex spp. | 6 | *Ulex Gallii*, P. | Trace |
| *Galium saxatile*, L. | 1 | *Pteris aquilina*, L. | 0 |
| *Potentilla erecta*, H. | 1 | | |

a flock on any particular location were in fact grazing a definite plant association, such as a bent–fescue slope or a Molinia sward. These concentrations of the individuals of a flock on a sward type were less marked at other periods of the year when search for green leafage over a wide area and irrespective of plant association became necessary. During this period the new leaves of Molinia appear in mid-May and are very palatable to sheep and cattle. The data in Table 3 show that its associated species, *Scirpus caespitosus*, is also well grazed. Agrostis and sweet vernal are appreciably more palatable than sheep's fescue and heath-grass, whilst

*Nardus stricta* is low in the scale relative to the other grasses. Both heath-grass and heath-rush (*Juncus squarrosus*) have lower values than in the winter and spring periods (Tables 1 and 2). It is probable that these species are not so well liked by the stock as certain other grasses and herbs during the summer months, but the presence of strong inflorescence stems on the plant must hinder the grazing of their leaves to some extent, a factor which, of course, affects all grasses and herbs to a greater or lesser degree during their inflorescence period. Among the species in Table 3 a distinct grouping of high, medium, and low relative palatability is discernible. The grasses chiefly occur in the high and medium groups, as also do the herbs field wood-rush (*Luzula campestris*) and ribgrass (*Plantago lanceolata*). The Carex species with yarrow (*Achillea Millefolium*) and heath-rush occur in the medium group. In the low-palatability group for this period are the herbs heath bedstraw, tormentil, bilberry, heather, and cross-leaved heath. It was observed that the mountain gorse (*Ulex Gallii*) was occasionally nibbled, probably by ponies; but the green fronds of bracken (*Pteris aquilina*) were not grazed at all, although they were very abundant on the lower-altitude fescue–bent slopes.

The relative palatability of the species in *autumn* is given in Table 4. The factors of discoloured and burnt or withered leafage become increasingly important in regard to the amount eaten as the autumn

TABLE 4. *The Relative Palatability of Species on Open Hill Grazings based on Scores of 0–10 (10 = most grazed)*

AUTUMN PERIOD

| *Species* | *Average scores* | *Species* | *Average scores* |
|---|---|---|---|
| *Festuca ovina*, L. | 7 | Carex spp. | 8 |
| Agrostis spp. | 10 | *Galium saxatile*, L. | 2 |
| *Nardus stricta*, L. (g) | 7 | *Potentilla erecta*, H. | Trace |
| ,, ,, (b) | 0 | *Juncus squarrosus*, L. | 4 |
| *Triodia decumbens*, B. | 9 | *Vaccinium Myrtillus*, L. (g) | 2 |
| *Anthoxanthum odoratum*, L. | 10 | ,, ,, (d) | 0 |
| *Luzula campestris*, D.C. | 2 | *Calluna vulgaris*, H. | Trace |
| *L. maxima*, D.C. | 2 | *Erica Tetralix*, L. | Trace |

(g) = green leafage, (b) = burnt leafage, (d) = discoloured leafage.

advances. Molinia becomes yellowed in colour early in September and then is only slightly grazed: the leaves become completely withered during the later months, and ultimately become deciduous. Nardus is also markedly affected by autumn burn, and its straw-coloured outer leaves and stems are completely avoided by the stock. Close observation again shows definitely that green plant-centres and any small, completely green plants are very well grazed, although the total quantity of edible Nardus leaves among the mass of burnt material of this species in late autumn may be small. In this connexion Smith [4] mentions the low economic value of *Nardetum* as grazing compared with other grass associations on the hills. The most palatable species in autumn are bent,

sweet vernal grass, and heath-grass, with sheep's fescue of good relative palatability but not sought after quite as readily as the foregoing. The species of Carex remain the greenest of the miscellaneous herbs and have the greatest relative palatability. The two species of Luzula are less grazed than earlier in the year, whilst the tip-burning of the heath-rush leaves and the retention of the inflorescence stem and seed-head throughout the autumn cause a lower relative degree of grazing. An interesting point at this period is the grazing of the bilberry leaves and stems. On hill-sides where this species may be found dominant, the bilberry provides green material that the sheep do not fail to utilize. Only very little grazing of the heather species was noted during the autumn months. A noticeable feature of the moister fescue–Agrostis slopes in late autumn and winter is the brilliant green of the Polytrichum species of mosses among the grass leaves that are becoming winter burnt. Although sheep have at times been abundant on such areas when notes have been taken, no evidence of the grazing of this moss has been observed. Also among the mosses of the drier fescue–Agrostis slopes of which Tansley [5] mentions species of Dicranum, Hypnum, and Hylocomium as usually occurring, they have been repeatedly observed to be pulled up by the closely grazing animals in their search for grass leafage, but if any moss has been eaten it is probable that it was not sought after but eaten incidentally along with the grass. With regard to the avoidance of herbage by the grazing animal, the writer has noticed that areas of semi-bogland with a covering of Molinia, tufted Scirpus, cotton-grass, and Sphagnum moss, with perhaps the addition of dense colonies of the common rush, can be the least sought after of all plant associations, particularly in late autumn and winter, when extensive areas of this nature have repeatedly been observed to be without a single sheep, although they have been plentiful on other associations, and with the absence of any fencing and therefore with the animals having free range. These areas of wet peat are the natural drainage ground of the higher slopes and represent a great acreage throughout the Plynlymon hills. They do, however, offer some fresh material to the animal in the spring and summer months which is made use of except where the degree of wetness merges into actual standing water.

*Conclusions.*—The main factors in the selection of herbage by the grazing animal on the hills and moorlands here under discussion are the nature of the species and its condition with regard to green edible leafage. The various grasses have undoubtedly formed the major portion of the food of the sheep and cattle; sheep's fescue, bent species, heath-grass, sweet vernal, Molinia, and Nardus together form the staple diet. It has, however, been seen that an important addition to the grasses is the miscellaneous herb group of plants; these may not form a very large proportion of the herbage in a fescue–bent or other grassland association, or they may comprise the bulk of the herbage in a particular area, such as a Scirpus with cotton-grass and Calluna association on moist peat. In the main, they are supplementary to and blend with the grasses in the chief plant associations of the hills.

Condition of the herbage has been shown to be chiefly that of the

presence of fresh green leaves whether of grass or herb, and whilst during the summer months the abundance of such herbage renders the selection by the animal almost entirely one of species preference, the coming of autumn and then of winter renders this factor of discoloration and 'burn' of the leafage the most important influence in selection. It has been shown that choice among the species is always exhibited by the grazing animal during the summer and throughout the winter. By the spring this species selection is reduced to a minimum as the green material becomes less and less available, for growth is invariably late on the Plynlymon hills. During April and early May in particular the remainder of the green leafage of the previous year's growth and the commencement of the initial spring growth are eaten with great avidity whether they consist of grass or miscellaneous herbs.

The flora has been the background of the study of the animal in its choice of individual species, and this study has shown the place, the season, and the nature of what herbage is actually consumed. There has also been an impression of the importance of greater utilization of the summer growth that occurs on these uplands. At that period the stocking is seldom heavy enough to keep down the prolific growth of certain of the hill species. Molinia is outstanding in this respect, and so to a lesser extent are the Juncus species (*J. communis* and *J. articulatus*), although these species are in a different category in regard to utilization by grazing, as the present data have shown. Phillips and Phillips [6], and Roberts [7] have commented upon the use to which small heaps of hay made from the summer growth of these species and placed at various points throughout the sheep-walks were of assistance to winter feed when this was the practice in earlier times. The former writers stress the importance of conserving Molinia in this manner as a means of avoiding heavy sheep losses during prolonged periods of snow and ice-cover. Roberts, in describing the farming practice on the Welsh uplands of a still much earlier period, shows how the annual summer migration of cattle herds and of personnel to the hills and the making of Molinia hay and of Juncus hay up the distant slopes of the hills ensured full utilization of the natural herbage available.

There remains the question of hill-sward improvement by employing methods determined by experimentation. Results have shown that the natural hill flora can be altered with respect to species-dominance by liming and/or fertilizing and a concentration of the grazing [8]; and further work has shown that even without fencing considerable quantities of wild white clover and certain amounts of the better grasses can be established among the hill herbage within 2 years by liming and fertilizing the natural swards. These experiments have been carried out at 950 ft. above sea-level within the area under discussion, and it remains to be seen whether like results would take place in the high plateau districts of the Plynlymon range as a whole. The present study has made it quite evident, however, that a revival of earlier hill-farming customs, together with sward-improvement technique on selected areas, would lead to still greater utilization of this extensive hill and moorland area in west-central Wales.

*Acknowledgements.*—The writer thanks Prof. E. T. Jones, Director of the Welsh Plant-breeding Station, and Miss R. Peter Jones for reading the manuscript.

## REFERENCES

1. J. Pringle and T. N. George, British Regional Geology: South Wales Dept. Sci. and Ind. Res., London, 1948.
2. W. E. J. Milton, The Palatability of the Self-establishing Species contributing to Different Types of Grassland. Empire J. Expt. Agric., 1933, **1**, 347–60.
3. J. H. Salter, The Flowering Plants and Ferns of Cardiganshire. Cardiff: Univ. Press Board, 1935.
4. W. G. Smith, The Distribution of *Nardus stricta* in relation to Peat. J. Ecol., 1918, **6**, 1–13.
5. A. G. Tansley, The British Isles and their Vegetation. Cambridge Univ. Press, 1939.
6. R. Phillips and Ll. Phillips, The Wintering of Mountain Sheep in Wales. J. Min. Agric., 1947, **54**, 217–22.
7. R. Alun Roberts, The Historical Development of Hill Farming in Wales. Agric. Progress, 1949, **24**, Pt. 1, 25–29.
8. W. E. J. Milton and R. O. Davies, The Yield, Botanical and Chemical Composition of Natural Hill Herbage under Manuring, Controlled Grazing, and Hay Conditions. J. Ecol. 1947, **35**, 65–95.

(*Received October 27, 1952*)

# SOME PROBLEMS OF ARABLE FARMING IN SOUTHERN RHODESIA

H. G. MUNDY

*(Ex-Secretary for Agriculture and Lands, S. Rhodesia)*

THE maintenance of soil fertility in the arable and grass lands of Southern Rhodesia has for many years presented very real problems to the Colony's farmers and agricultural research and advisory officers. Considerable progress appears now to be being made, but no completely proven and satisfactory solution is yet in sight.

*Introduction.*—The total area of Southern Rhodesia is approximately 150,333 square miles and this is divided into Mashonaland of 80,344 and Matabeleland of 69,989 sq. m. A further subdivision gives to Mashonaland twenty-four so-called Native Districts and to Matabeleland thirteen. In each district, except the Salisbury district, an appreciable area has been set aside for the exclusive use or benefit of the African population. Close on 22 per cent. of the Colony's land, 33,011 sq. m., is demarcated as Native Reserves, and other areas have been declared Native Purchase Areas and Special Native Areas. Still further areas are as yet 'unassigned', having thus far been allocated neither to European nor to African occupation.

Much of the total land area is still but sparsely, if at all, occupied either by human beings or domesticated livestock. Low and unreliable rainfall, absence of permanent surface-water, and the presence of tsetse fly are the primary causes; these conditions are mainly met with in the north-west and south-east, where Southern Rhodesia borders with Bechuanaland, Northern Rhodesia, the Transvaal, and Portuguese East Africa.

Dependent upon the expected annual rainfall (usually confined to $4\frac{1}{2}$–$5\frac{1}{2}$ months with a total precipitation varying from 20–40 in. in that period), farms in the European area are mostly of about 2,000–6,000 acres, the larger generally being in the lower rainfall areas. Cattle ranches, also generally in low-rainfall zones, usually measure 20,000–60,000 or 70,000 acres, with a few very much larger. Unimproved natural grassland, often heavily timbered, will seldom maintain more than one head of cattle per 20–30 acres without extra feeding. The more arid Low Veld areas in which the grazing is particularly nutritious—whether green or mature—are unfortunately highly sensitive to overgrazing with consequent tramping out of the grasses. The Colony now has some 6,000 licensed farmers, each farming more than 100 acres, and mostly on farms of 2,000 acres or larger.

*Soil formation.*—The character of the soils of Southern Rhodesia is primarily influenced by the underlying rock formations, rather than by climate or vegetation. Over the total area, probably not less than 75–80 per cent. of the soil is of a light sandy character, generally low in fertility and often lacking in depth. Soils derived from Basement Schists

[Empire Journ. of Exper. Agric., Vol. 21, No. 82, 1953.]

account for about 14 per cent. of the whole area and are reflected in red and brown clay-loams with heavier black, but usually ill-drained, land in the valleys. These red-brown soils are of good inherent fertility but, as will be shown later, rapidly lose this quality under a monocultural system, or even under any rotation of crops which does not provide for the regular and frequent return of large amounts of organic matter to the land. Alluvial soils represent not more than 0·4 per cent. of the total land-area and the Colony can boast of no soils of lasting fertility comparable to the prairie land of Canada or the steppes of the U.S.S.R.

Under the soil and climatic conditions described and with generally an abundant supply of cheap native labour (now rapidly disappearing in favour of employment in towns), an extensive rather than an intensive system of farming has not unnaturally been adopted.

*Early agriculture.*—Little more than 60 years have passed since the Pioneer Column entered Southern Rhodesia. Pioneer settlement on the land was delayed by native risings and the Anglo-Boer War. Further disruption to a very small and widely-scattered farming population was occasioned by World War I, when many men completely abandoned their very primitively developed farms to join the Forces.

The Colony's agriculture had been built up on maize, and is being stabilized on this crop and Virginia flue-cured tobacco, both of which are combined with livestock, particularly cattle and pigs. The first preoccupation of the settlers was naturally to grow their own food requirements and that of their native labourers, and the crops grown by the indigenous Africans were the first to be grown on a larger scale by European farmers: maize, groundnuts (peanuts) and cowpeas or Kaffir beans (*Vigna catjang*). To these were added on a small scale wheat, barley, potatoes, sunflowers, and vegetables. But for many years maize, barley, and wheat were the only grains that could be sold in quantity; and the only agricultural products exportable at a profit were maize and sometimes groundnuts and sunflower seed, such wheat as could be grown being required for home consumption.

Few of those who took up Rhodesian farms between 1900 and 1930 were experienced farmers. Many came from the Cape, Natal, or the Transvaal, where farming methods were still very primitive. Not a few came from the United Kingdom with no previous farm training or experience. All, including those who had followed every other conceivable mode of life, regarded farming as 'easy money'!

Those who remember world prices for maize, up to about 1916–17, need not be reminded that imports of this grain f.o.b. U.K. ports were worth about £6 to £7 per short ton of 2,000 lb. By concentrating on large, flat, white maize, Southern Rhodesia obtained 2*s.* 6*d.* to 5*s.* per ton above the prices ruling for maize from other sources. But when the cost of sacks, railage, and sea-freight had been met, the average grower producing 8–10 bags (200 lb. each) of maize per acre was left with a profit of not more than 2*s* to 3*s.* per bag. It was obviously necessary for farmers to aim at large-scale production, and the average Crown Land farm in the higher-rainfall areas offered for settlement by the then Administrators of the Colony, the British South Africa Company, was in con-

sequence surveyed at 2,000–3,000 acres in extent, and was expected to possess not less than 25–40 per cent. of good potential arable land. Virginia flue-cured tobacco was still far from an established industry, and the principal saleable products from sand veld farms were cattle and butter-fat and winter-grown wheat, barley, and oat forage, mainly on moisture-retaining valley soils but sometimes under irrigation.

*Maintenance of soil fertility.*—Under a primitive system of cattle-farming the animals were expected to thrive on the summer pasturage and subsist on the dry winter grasses, aided to a limited extent by grazing on the dry stalks and leaves of the maize or other crop residues. There being little paddock fencing, cattle were for the most part penned at night in open kraals where their droppings were exposed to heavy rain and bleaching during the summer and were converted into powdery dust as the dry season advanced. The total amount and the value of manure thus made were naturally small and under a system of farming, largely monocultural through lack of markets, the benefit of applications of 8–10 t. per acre of such manure did not extend beyond two seasons. The root residues of such legumes as cowpeas and velvet beans when ploughed under return a limited measure of fertility to the soil but until recently, when improved harvesting machinery became available, these were awkward crops to reap and in any case there was little market for them.

Early experiments conducted by the writer on the Salisbury Agricultural Experiment Station and the Gwebi Demonstration Farm clearly indicated that the major governing factor in the fertility of Rhodesian soils was organic matter. Where by any means this, with its accompanying nitrogen, could be maintained in good supply and was assisted by small applications of phosphatic fertilizer, fertility would continue at a reasonably high standard. Where the humus-content of the soil was seriously depleted, crop yields became entirely uneconomic. The red, brown, and black clay loams of the Colony in a virgin state and after being under grass and bush for many years are at best only moderately rich in organic matter and low in nitrogen, phosphates, and potash. The sandy soils—on which grass growth is usually sparse—even when first broken, contain very little organic matter and are still lower in their contents of nitrogen, phosphates, and potash.

*Green-manuring.*—Resulting from the experiments referred to, I was able while controlling the Field Husbandry experimental work of the Department to demonstrate that if green-manure crops consisting of cowpeas (kaffir beans), velvet beans, Dolichos beans, or better still sunn hemp, or one or other of these in combination with sunflowers, were ploughed under with sufficient frequency, and if 150–250 lb. per acre of phosphatic fertilizer was applied either to the green-manure crop or to the first or second succeeding cereal crop, yields of 8–14 bags of maize per acre or 5–8 bags of wheat an acre could be expected more or less indefinitely. Initially, one green-manure crop was recommended every fourth year followed by maize, then by another crop not a cereal, followed by maize again. A number of the more progressive Rhodesian farmers adopted this system with variations but many failed to do so—some through apathy, and some through believing that they could not

afford to throw a considerable part of their arable land out of cash crops each year to make space for the green-manure crops.

Where green-manuring was neglected by maize growers soil erosion was accentuated, and soil fertility was reduced within a few years to so low an ebb that the land would not produce more than 1–3 bags of grain an acre and, in an adverse season, even less. On the other hand, where arable lands have been green-manured once every fourth, third, or alternate year, accompanied by reasonable applications of phosphatic fertilizer, fertility has been well maintained and under the last-mentioned system has been kept at a very high level. Although it may fairly be claimed that green-manuring has been the saviour of the soil fertility of Mashonaland it has, for some reason which I am unable to explain, proved less advantageous under the lower rainfall conditions of Matabeleland. There, the turning in of the stubble of an annual legume, such as one of those named, has usually proved as beneficial as turning down the entire crop. Unfortunately, under Rhodesian conditions of $4\frac{1}{2}$–$5\frac{1}{2}$ months of summer rains and the remainder of the year rainless, land sown to a green-manure crop returns neither cash nor fodder for farm consumption in that particular season. This is obviously a very serious disadvantage, yet despite it some of our most successful maize-growers practice green-manuring every other year. On irrigated land, the green crop can usually be grown with the help of the summer rains followed by a winter-sown, irrigated cereal.

*Compost.*—Following the publication of the late Sir Albert Howard's *Agricultural Testimony*, much work was done by the Field Husbandry branch of the Southern Rhodesian Department of Agriculture and by farmers in testing various methods of making farm compost. Here again, however, under our rainfall conditions vegetable wastes can be converted into compost only during the rainless months provided considerable supplies of water are available, or in small quantities by yard-fed livestock.

There is no doubt of the manurial value of compost when made with sufficient animal droppings and urine, and in this Colony applications of 7–10 t. per acre will raise the fertility level of the soil very markedly over a period of 2 years. In this respect its effect is very much like that of the ploughing under of a heavy legume crop, but its advantage is that the land can be kept in directly profitable production. However, the making of the very large amounts of compost required on a Rhodesian farm with 500–1,000 acres under crops each year is a major undertaking, and a costly one if all the labour required until the material is spread on the land is taken into account. Most arable farmers in Southern Rhodesia today make compost in varying amounts, in some cases up to 1,000 tons a year. But what is even 1,000 t. applied over 700–1,000 acres under the plough, with 7–10 t. an acre required every 2–$2\frac{1}{2}$ years, and the short grass leys crying out desperately for similar treatment?

*Organic matter in Rhodesian soils.*—Whether it be due to the intense dryness of our 6–7 winter months, very high temperatures before the rains break, and during droughty intervals, or to the absence of earthworms and their replacement by white ants, or to a combination of all

these circumstances, it remains an unfortunate fact that by whatever means organic matter is supplied to the soil it is very rapidly dissipated. Following the ploughing under of a sunn hemp crop giving 12–20 t. of green fodder to the acre no sign of the humus so supplied will be observable 2–2½ years later. The same is true of a 7–10 t./acre dressing of compost or on land which before breaking has been for years under a rank growth of grass, or less grass combined with bush and tall timber. Soil structure, built up by a period under grass ley, quickly disappears, and as yet no proved method can be claimed to have been found to take the place of green-manuring with a legume at very short intervals or of heavy applications of dung or kraal-compost every second or third year. The remarkable efficiency in Mashonaland of green-manuring with a suitable legume combined with an application of phosphatic fertilizer has been shown during the past season on the farm 'Calgary' owned by Mr. H. V. Wheeler, about 14 miles distant from Salisbury. Using hybrid seed maize and immediately following a green-manure crop, Mr. Wheeler tells me he has produced an average of 36 bags of maize per acre (a bag of maize weighs approximately 200 lb.) over an area of 180 acres. Admittedly the land used has always been exceptionally fertile and has been well farmed, but it has been under regular cropping for at least 30 years. As previously mentioned, innumerable other examples of the efficacy of green-manuring as a means of maintaining soil fertility in the higher rainfall areas of Mashonaland could be quoted. The records of experiments carried out on the Salisbury Agricultural Experiment Station and of the Gwebi Demonstration Farm (now the Gwebi Agricultural College) over the past 30 years, as well as those of numerous well-established farmers, have borne convincing evidence of this fact.

*Recent research* v. *old-established practice*.—Under this heading I refer to a continuation of green-manuring and the application of 150–200 lb. per acre of phosphatic fertilizer, both at intervals of not more than 2–3 years. Alan H. Rattray states that the object of extended trials was to determine the effect on yield of maize when a legume is grown in the rotation at varying intervals, and used for (1) green manure, (2) as a hay crop, and (3) for seed production. In each instance the legume crop either alternates annually with maize, or is followed by two, three, or four successive maize crops. Hybrid maize has been sown each year and each plot has been replicated eight or ten times. The experiments cover the seasons 1945–6 to 1950–1.

Over twelve seasons alternate maize and green-manure crop has given the highest average yield of 14·9 bags (each of 200 lb.) per acre. The next highest yield, 11·5 bags over the same period, occurred when the green-manure crop was followed by two successive crops of maize; and the next best, 11 bags, where the maize and the legume utilized as a hay crop were alternated. Over the 6-year experimental period, starting 1945–6, the total number of bags of maize obtained from 1 acre has been: 38·5 from alternate maize and green manure, 37·7 bags from green-manure crop followed by two crops of maize, 37·9 from green manure followed by three successive crops of maize, and 32·7 bags from green manure followed by four successive maize crops. The next highest pro-

duction from the one acre invariably followed the legume used as hay crop, the maize yield being much less where the legume was reaped as a seed-crop.

Rattray comments that 'in comparison with other maize trials on the Station, although no special manurial or fertilizer treatment is accorded them, yields in the better systems of this trial remain disappointingly low'. The yields of maize following the legume crop reaped either for hay or for seed fall considerably short of the maize yield following the same legume crop ploughed under, but Rattray's report concludes: 'System A, which receives 150 lb. of phosphates annually and has velvet beans (mucuna) ploughed under as a green manure every second season, has a mean maize yield of 14·9 bags an acre for the 12 seasons, a figure far exceeded in the variety and distance planting trials in a normal season. A possible explanation is that this rotation is too narrow, whilst on other parts of the Station a wider range of crops of different types is rotated, resulting in a healthier and better system of farming.' As against the average 14·9 bags of maize over the 12 years with alternate green-manuring, a 4-year grass ley followed by four successive crops of maize gave an average of 8 bags an acre, whilst a 3-year grass ley followed by two crops of maize, followed by a green-manure crop and two more crops of maize, gave an average of 9·7 bags of maize per acre over the 12-year period.

*Legumes for grass leys.*—None of the well known and popular grasses or perennial legumes of European or American agriculture is capable of surviving in the 6 or 7 months of drought and heat in Southern Rhodesia. A considerable variety in perennial grasses, mostly of African origin, is now being grown for short 3 to 5-year leys. But, although these will persist, and make some spring growth before the rains commence, and grow luxuriantly in summer and early autumn, we have yet no recognized perennial legume to establish with these grasses, which like the clovers, lucerne, &c., will enrich the soil in nitrogen, stimulate the grass growth, and generally build up the fertility of the soil until such time as the ley is broken down for a return to annual crops. Numerous legumes are under trial for this purpose but none as yet appears outstanding as a 'dry-land' crop. Under gravity or spray irrigation the problem is easy, but our area of irrigable arable land is very small in relation to the acreage of 'dry land' on which Rhodesia must produce if we are to be self-supporting. An interesting and unexplained phenomenon is that many of Southern Rhodesia'a trees and veld shrubs are legumes, producing root-nodules in considerable abundance, though never has it been observed that grasses growing adjacent to these legumes derive any benefit from their proximity. Yet, white clover or subterranean clover growing in moist or irrigated land imparts to nearby grasses increased vigour and verdure!

*Short-term grass leys.*—Our research workers are concentrating much attention on grass leys laid down for 3–6 years as a means of rebuilding soil structure and raising soil fertility. They already have a range of useful hay and grazing grasses which make strong growth during the rains and remain palatable and of fair feeding-value, even when mature

and dry during winter. They have yet to find the right nitrogen-gathering legume to combine with these grasses, and which is capable without irrigation of surviving the long rainless months, has a high feed-value, and is well liked by stock. A great variety of legumes introduced from all parts of the world is under trial, and among the more promising appear to be a number of Indigoferas.

On one Research Station emphasis is being placed on Napier fodder (Elephant grass, *Pennisetum purpureum*) planted in rows 6–7 ft. apart and interplanted with velvet beans (mucuna) each rainy season. Within 12 months the roots of the Napier fodder are said to meet across the rows, and each spring are cut close to the plants by deep, 'ripper' cultivation. The mixed crop is ensiled and is fed with grass hay to beef steers on an adjacent land where after 4 years of similar treatment the stools of the Napier fodder and residue of the velvet bean crop have been ploughed under. Suitable artificial fertilizer is applied each year and the fodder is cut with a tractor-drawn mower. This system appears to offer good prospects, particularly for the farmer producing whole milk.

The Colony possesses a numerous and highly qualified staff of research workers and executives in every branch of the agricultural industry. With the progress already made, and despite the uncertainties in many directions, Southern Rhodesia has this year attained her maximum agricultural production: 2·6 m. bags of maize from 374,000 acres planted, 11 m. lb. of seed cotton from 37,000 acres, and some 103 m. lb. of Virginia flue-cured tobacco from 193,000 acres. The complete failure of the rains at the end of January reduced the flue-cured tobacco to 96·5 million lb., but in quality it was one of the best the Colony has yet grown. With greater knowledge of the problems here discussed and with the inevitable change-over from extensive to a more intensive farming, each of these outputs can be increased by at least 50 per cent., with a similar increase in the production of subsidiary crops and livestock.

*The phosphate problem.*—Saunders and Salmon in a recent report state that "The general conclusion is that no significant response to phosphate fertilization has been obtained during the past 9 years at this Station on maize lands which have been maintained in fertility by introducing a leguminous green-crop rotation (presumably a leguminous green-manure crop) every third year.' So now, after 30 years' trial and error, with innumerable instances of the greatest success, the efficacy of frequent green-manuring and regular applications of phosphatic fertilizer are both brought under doubt. The short, 3 to 5-year grass ley, unless it can be combined with a perennial, nitrogen-gaining and nitrogen-storing legume exposes the following crop, in its early stages of growth to nitrate starvation. This, at present, can be counteracted only by a dressing of sulphate of ammonia or nitrate of soda, costing some £5 per acre. And thus, the problem of how Southern Rhodesia can maintain the fertility of great areas of arable land annually under crops on the majority of farms in the higher rainfall zones is still very much in the melting-pot! Without more convincing and general evidence of the failure of frequent green-manuring with the legumes mentioned, in conjunction with applications of phosphatic fertilizer, Rhodesian arable farmers will be

wise to continue to rely on these two tried 'friends' of 30 years' standing. A great amount of research work, backed by practical trial by practical farmers, is required before Southern Rhodesia will be in a position to claim she has devised economical systems of arable-land management suited to her varying soil types and rainfall conditions.

*References.*—The experiments referred to are described in the *Rhodesia Agricultural Journal* and (mostly) in reports of the Salisbury Agricultural Experiment Station. The references are H. G. Mundy and H. C. Arnold (1922–48); Alan G. Rattray (May–June 1952); A. G. Rattray and B. S. Ellis (July–Aug. 1952). Articles on phosphate in Rhodesian soils by D. H. Saunders and R. C. Salmon (May–June, 1952); B. S. Ellis (July–Aug. 1952); I. McDonald and C. I. Shepherd on green-manuring (July–Aug. 1952).

(*Received October 21, 1952*)

# THE MANURING OF *HEVEA BRASILIENSIS* AT DARTONFIELD, CEYLON

D. H. CONSTABLE[1] AND G. E. HODNETT[2]

A FERTILIZER experiment on *Hevea brasiliensis* has been in progress at Dartonfield, Ceylon, since 1938. The object of this paper is to report the results obtained in relation to the production of girth in the early years and to subsequent yield of rubber.

## *Description of the Experiment*

The experiment was laid down on a light sandy soil, typical of the Kalutara District, in order to determine which of the main plant nutrients, nitrogen, phosphate, and potash, were required (*a*) to produce sufficient girth to permit tapping as early as possible, (*b*) to give the best subsequent annual yields of rubber.

The treatments consisted of all combinations of presence and absence of:

| | *Before tapping* (oz. per tree per year) | *After tapping* (oz. per tree per year) |
|---|---|---|
| Sulphate of ammonia (20% N) | 15 | 35 |
| 'Saphos' (rock) phosphate (30% $P_2O_5$) | 10 | $23\frac{1}{3}$ |
| Muriate of potash (60% $K_2O$) | 5 | $11\frac{2}{3}$ |

These rates provided equal amounts of each plant nutrient. Treatment with compost at an average rate of 50–60 lb. per tree was also included for comparison with the inorganic fertilizers. The compost was made from town refuse approximately according to the Howard method [1]; as its composition was rather variable, inorganic fertilizers were added to maintain its nutrient-content at about the same level as in the above applications.

It was found preferable to apply the fertilizers in three or four doses per year, each time forking in lightly at about the outer circle of the roots or midway between the trees, whichever was the less. Sulphate of ammonia was not applied during the period December to April inclusive, in order to reduce the tendency to a soft and odium-prone vegetative growth.

The nine treatments were arranged in six randomized blocks, each of a different clone (TJ 1, PB 183, W 259, HC 28, PB 86, PB 186). Each plot consisted of forty trees of which the central sixteen constituted the experimental plot, the remainder forming the guard rows. With such necessarily large plots, and blocks not as compact as desirable, owing to the difficult terrain, the whole experiment occupied an area of $19\frac{1}{2}$ acres.

The girth of every tree has been measured annually since 1941, and the yield per plot each year since tapping began in 1944. Tapping commenced on an experimental plot when at least twelve trees had reached a girth of 18 in., but no trees were tapped before attaining this girth.

[1] Rubber Research Institute of Ceylon, Agalawatta, Ceylon.
[2] Rothamsted Experimental Station, Harpenden, Herts., England.

[Empire Journ. of Exper. Agric., Vol. 21, No. 82, 1953.]

S/2, d/2, 100 per cent. tapping [2] has been used consistently and losses on untapped rainy days have not been made up.

The plot yields were determined by sampling. Once a month the volume of latex obtained from each plot by the normal daily tapping was measured. From this a 50-ml. sample was taken, coagulated in an aluminium cup, milled and rolled out to a sheet, dried in air and weighed. The yield of dry rubber in grams per plot was then calculated. To this was added the weight of scrap rubber collected. The yields were converted to lb. per acre on the basis of 120 tappings per year. Since 1948, a 50-ml. sample has also been taken from the total daily tapping and this has provided a very accurate check on the total yield of the area.

## *Results*

TABLE 1. *Treatment Effects of Fertilizers on Mean Girth of Trees*

*Inches*

| *Year* | *Mean*• | *Main effects* | | | *Interactions* | | | | | *Response to compost* | *S.E.*† |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | N | P | K | NP | NK | PK | NPK | *S.E.* | | |
| 1944 | 16·21 | +0·82 | +2·85 | +0·51 | +0·15 | +0·25 | +0·05 | −0·63 | ±0·49 | +2·98 | ±0·98 |
| 1951 | 26·55 | +0·66 | +2·55 | −0·06 | −0·60 | +0·51 | −0·03 | −0·50 | ±0·47 | +3·65 | ±0·93 |
| Change 1944–51 | 10·34 | −0·16 | −0·30 | −0·57 | −0·75 | +0·26 | −0·08 | +0·13 | ±0·49 | +0·67 | ±0·98 |

• Excluding plots treated with compost.
† Applies also to difference in responses to compost and average response to N, P, or K.

Table 1 shows that the only significant responses in terms of girth were to phosphate and compost both in 1944, the last year before the physiology of the trees was disturbed by tapping, and again in 1951. These 2 years provided sufficient indication of the way in which the trees were developing, whilst the analysis of the change in girth between 1944 and 1951 shows that these beneficial effects were unaffected by tapping. The responses to phosphate and compost did not differ significantly; the response to the latter may, in fact, be due simply to its phosphate-content. However, in order to elucidate the action of compost it would be necessary to include it in a factorial experiment with inorganic fertilizers.

The treatment effects (main effects and interactions) were calculated by the standard methods for factorial experiments [3]. The standard errors were derived from the remainder-clones interaction mean square (25 d.f.). This method, which is illustrated in Table 5 for yield, was used in order to investigate a possible clone-fertilizer interaction, since there was no separate estimate of error, clone differences having been confounded with block differences.

A test of the nitrogen-clones interaction mean square against the above estimate of error showed that it was significant at the 5 per cent. level ($F(5, 25) = 3{\cdot}14$ compared with 2·60) for the 1951 data. This result was not confirmed, however, by the 1944 data, nor was it supported by a significant nitrogen effect in either of the years. Furthermore, since the experiment was not designed to provide a proper test of

TABLE 2. *Total Yields of Dry Rubber in lb. per acre*

| Years | Block | Clone | Treatment | | | | | | | | | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | — | N | P | K | NP | NK | PK | NPK | *Compost* | |
| 1944–7 | 1. | TJ 1 | 1,320 | 975 | 1,695 | 570 | 1,695 | 1,530 | 1,545 | 1,440 | 1,905 | 12,675 |
| | 2. | PB 183 | 360 | 300 | 1,410 | 630 | 1,410 | 465 | 840 | 1,260 | 660 | 7,335 |
| | 3. | W 259 | 1,200 | 975 | 855 | 915 | 1,185 | 735 | 1,260 | 1,185 | 795 | 9,105 |
| | 4. | HC 28 | 1,290 | 1,050 | 1,470 | 1,530 | 1,515 | 1,485 | 1,755 | 1,770 | 1,425 | 13,290 |
| | 5. | PB 86 | 1,245 | 945 | 1,980 | 870 | 2,115 | 1,305 | 2,265 | 1,995 | 1,695 | 14,415 |
| | 6. | PB 186 | 1,095 | 1,365 | 1,440 | 90 | 1,890 | 1,845 | 1,830 | 1,770 | 1,950 | 13,275 |
| | | *Total* | 6,510 | 5,610 | 8,850 | 4,605 | 9,810 | 7,365 | 9,495 | 9,420 | 8,430 | 70,095 |
| 1948–50 | 1. | TJ 1 | 2,595 | 2,325 | 3,420 | 1,515 | 3,270 | 2,940 | 2,415 | 3,045 | 3,465 | 24,990 |
| | 2. | PB 183 | 1,215 | 1,395 | 2,310 | 1,335 | 1,815 | 1,395 | 2,115 | 2,130 | 2,070 | 15,780 |
| | 3. | W 259 | 2,730 | 1,785 | 1,890 | 1,320 | 1,485 | 1,515 | 2,130 | 1,695 | 1,620 | 16,170 |
| | 4. | HC 28 | 2,040 | 1,680 | 2,370 | 2,205 | 2,085 | 2,130 | 2,445 | 2,115 | 1,830 | 18,900 |
| | 5. | PB 86 | 2,820 | 2,505 | 3,360 | 2,385 | 2,895 | 2,715 | 2,760 | 3,105 | 2,745 | 25,290 |
| | 6. | PB 186 | 2,175 | 2,535 | 2,505 | 1,305 | 2,775 | 3,090 | 2,700 | 2,775 | 3,315 | 23,175 |
| | | *Total* | 13,575 | 12,225 | 15,855 | 10,065 | 14,325 | 13,785 | 14,565 | 14,865 | 15,045 | 124,305 |
| 1944–50 | | *Total* | 20,085 | 17,835 | 24,705 | 14,670 | 24,135 | 21,150 | 24,060 | 24,285 | 23,475 | 194,400 |

clone-fertilizer interactions, this interaction (which is also discussed later in connexion with yield), cannot be regarded as established.

The total yield of each clone for the various treatments is given in Table 2. In the period 1944–7 the yields, although of economic importance, were generally small. This was due in part to some of the plots, notably those receiving potash alone, remaining untapped until 1946. During the last 3 years (1948–50) the yields were more stable, so that the mean for this period may be taken as an indication of the steady yielding capacity. From the total yields with the various treatments for the whole period (1944–50), it is seen that the treatments may be arranged in three groups, the mean yields of which are given for each year in Table 3. This table shows the beneficial effect of phosphate and also the depressing effect of potash alone. A similar deleterious effect with potash has been noted elsewhere [4, 5].

TABLE 3. *Mean Yields of Dry Rubber in lb. per acre*

| | *1944–5* | *1946* | *1947* | *1948* | *1949* | *1950* | *Total* |
|---|---|---|---|---|---|---|---|
| With phosphate . . | 441 | 511 | 614 | 747 | 938 | 799 | 4,050 |
| Without phosphate (excluding potash alone) . | 170 | 374 | 538 | 647 | 797 | 755 | 3,281 |
| With potash only . . | 108 | 275 | 385 | 463 | 600 | 615 | 2,445 |

Table 4 shows the treatment effects of the fertilizers on the mean yield of dry rubber per year for the period 1946–50, and the complete analysis of variance for this period is given in Table 5. The yields for the first 2 years were not included in this analysis, since the yields had been combined and a number of plots had not been tapped.

TABLE 4. *Treatment Effects of Fertilizers on Mean Yield of Dry Rubber (1946–50) in lb. per acre*

| | *Main effects* | | | *Interactions* | | | | | *Response to compost* | |
|---|---|---|---|---|---|---|---|---|---|---|
| *Mean*• | N | P | K | NP | NK | PK | NPK | *S.E.* | | *S.E.*† |
| 652·5 | +19·8 | +138·2 | −39·0 | −31·5 | +79·1 | +13·8 | −49·2 | ±28·1 | +53·5 | −56·0 |

• Excluding plots treated with compost.
† Applies also to difference in response to compost and average response to N, P, or K.

With yield, as with girth, phosphate gave a significant response, although in this case the response to compost was not significant. Table 4 also shows that there were no appreciable interactions involving phosphate. There was, however, the nitrogen-potash interaction, which was rather anomalous, since neither nitrogen nor potash had significant effects. This is due to the very low yields on the plots receiving potash only.

The way this interaction arises may be seen by considering the responses to nitrogen in the presence and absence of potash, with phosphate absent and with phosphate present, using the data of Table 2.

It will then be observed that in the absence of phosphate there was a large positive response to nitrogen in the presence of potash because of the low yields with potash alone, whereas under the other conditions the response to nitrogen was negative. It thus appears that the main contribution to the nitrogen-potash interaction is from the plots without phosphate. The difference in the nitrogen-potash interaction in the presence and absence of phosphate is reflected in the fairly large three-factor interaction (see Table 4). It should be noted also that the response to nitrogen and potash together, which is given by N + K = −19·2 (see Table 4), is very small.

TABLE 5. *Analysis of Variance of Yields (1946–50) in lb. per acre*

| | *D.F.* | *S.S.* | *M.S.* |
|---|---|---|---|
| | | 100 × | 100 × |
| Clones (blocks) | 5 | 38,707 | |
| Treatments | 8 | 18,950 | 2,369 |
| Nitrogen × clones | 5 | 6,754 | 1,351 |
| Phosphate × clones | 5 | 3,665 | 733 |
| Potash × clones | 5 | 1,805 | 361 |
| Remainder × clones | 25 | 11,765 | 471 |
| Years | 4 | 61,306 | |
| Years × treatments | 32 | 2,761 | 86 |
| Years × clones | 20 | 13,876 | 694 |
| Years × treatments × clones | 160 | 12,127 | 76 |
| Total | 269 | 171,716 | |

The responses to the treatments did not vary significantly from year to year. The years-treatments interaction mean square (Table 5) when tested with the appropriate error mean square gives $F(32, 160) = 1{\cdot}13$, compared with 1·45 at the 5 per cent. level of significance.

The possibility of a clone-fertilizer interaction was investigated in the same manner as for girth. The nitrogen-clones interaction was again found to be significant at the 5 per cent. level ($F(5, 25) = 2{\cdot}87$ compared with 2·60). This effect is also a reflection of the large positive responses to nitrogen, especially in the presence of potash, on two of the blocks (clones TJ 1 and PB 186) with negative responses on the other blocks.

To investigate clonal differences and possible interactions with fertilizers, designs will be required in which clones are introduced as a factor with proper replication. For this purpose $2^n$ or $3^n$ type designs in blocks of eight or nine plots are possible by means of confounding, if it is feasible to use the same size of plots for clones as for fertilizer treatments, and provided that the number of clones is respectively a power of 2 or 3. If, however, it is necessary to arrange the clones in blocks, then designs in blocks of four plots are available using split-plot confounding [6].

In view of the results obtained in this experiment, the primary object of future experimentation will probably be to determine the optimum amount of phosphate to be used, at least on this soil type.

*Summary.*—The data on girth of the trees and yield of rubber obtained during the first 13 years of a fertilizer trial on *Hevea brasiliensis* at Dartonfield have been analysed. With both girth and yield the principal response was to phosphate. The results of this experiment did not indicate any appreciable interactions.

*Acknowledgements.*—We express our appreciation of the help given by Dr. F. Yates and Mr. H. D. Patterson during the preparation of this paper.

## REFERENCES

1. A. Howard and Y. D. Wad, Waste Products of Agriculture. Oxford Univ. Press, 1931.
2. —— —— The International Notation for Tapping Systems. Revised version, May 1940. J. Rubb. Res. Inst. Malaya. Comm. 247.
3. F. Yates, The Design and Analysis of Factorial Experiments. Imp. Bur. Soil Sci. Tech. Comm. No. 35.
4. H. Fairfield Smith, Effect of Fertilizers on Growth of Hevea. J. Rubb. Res. Inst. Malaya. Comm. 266.
5. C. G. Akhurst and G. Owen, Manuring Experiments on Young Rubber Trees. Ibid. Comm. 267.
6. W. G. Cochran and G. M. Cox, Experimental Designs, Wiley, 1950.

(*Received December 24, 1952*)

# EXPERIMENTAL EVIDENCE OF CLONAL VARIATION AFFECTING YIELD IN POTATOES

T. M. W. DAVIDSON[1] AND D. N. LAWLEY[2]

WHENEVER selection of potato plants is carried out with a view to improving the health of stocks, the possible presence of high- and low-yielding clones becomes of first importance. With the establishment of the Virus-tested Seed Scheme in Scotland, where single clones are tested for virus X, multiplied for a few years, then passed into the general seed trade, the progeny from any one clone may run into hundreds of acres. It is desirable therefore, that should there be clonal variation in yield, only families with high-yielding capabilities should be used.

In Australia [1] it was found that from the old-established varieties of Up-to-Date, Early Carmen, and Brownell, clones of earlier and later maturity than the normal could be selected readily. Some were distinct (medium and late Brownell) whilst in others (Up-to-Date) few foliar differences were observed. Although Bald [1] is more concerned with maturity variants suited to certain environments he found 'variant clones of Up-to-Date and Brownell that are consistently capable of outcropping other clones of similar maturity when grown under certain environmental conditions'. To date the main clones of differing maturity observed in Scotland are those of semi-bolter and bolter types. Variations of foliage form and colour of flower and tuber are found, but before 1945 no variation had been found which outcropped the typical plant of the variety and retained the same maturity date as the latter [2]. One may safely assume, as did Bald, from the evidence of frequent changes in the noticeable characters which are familiar to seed-potato growers, that comparable changes in the more obscure characters, i.e. yielding capacity, occur at least with equal frequency.

Clone testing has been carried out on a large scale in Holland [3] since 1950 to prevent low-yielding, virus-tested clonal families from reaching the open market. The tests are carried out at three centres over a period of 3 years by the General Netherlands Inspection Service. It has been shown that the productive capacity of certain clones is higher than that of others, no abnormalities being manifest. The results are mainly based on the yields from small plots in uniform fields and it is not stated whether these have been statistically analysed.

The findings of workers in other countries indicate that in established potato varieties, clones of differing yielding capacity arise which may or may not differ from the normal in appearance. The latter are important from the point of view of recognition, and, once identified, may then be propagated to give increased yield. To the many specialized seed-potato growers who practise plant-selection as a means of improving their stocks, the result of this experiment will be of interest and any improvement in crop-yield resulting from the work will doubtless benefit all potato growers.

[1] Department of Agriculture for Scotland.
[2] Mathematical Institute, University of Edinburgh.

[Empire Journ. of Exper. Agric., Vol. 21, No. 82, 1953.]

*Methods and materials.*—Assuming that yield variants arise in the same proportion as gross variants, then the older the variety the greater the proportion of yield variants which can be expected in an apparently normal crop. On this assumption an old variety was chosen for the experiment. Another requirement was to exclude as far as possible virus disease, particularly that caused by virus X. In the virus-tested stocks available at the time, choice of variety and more particularly of clones was too restricted. This limited the choice to varieties field-immune from virus X and A, e.g. Epicure and King Edward. The former, however, was ruled out because of the frequent occurrence in it of bolters and semi-bolters. King Edward may not be entirely ideal as every plant of this variety is a symptomless carrier of the virus E (Para-crinkle), but it was adopted as the best available at the time.

In 1950 twenty typical King Edward plants were chosen from two large stock seed plots growing at East Craigs, Edinburgh, and were lifted at maturity. From these, eight clones were selected to give the maximum weight range. Five setts from each were planted in five randomized blocks in 1951 and forty setts in forty randomized blocks in 1952. The plots were anti-blight sprayed in both seasons and no diseases were observed on the haulms or the tubers. The plots were kept under observation and were found to be free from noticeable virus diseases and foliar variations and to mature evenly.

*Results.—1950.* Eight clones selected from plots growing at East Craigs, in order of weight.

| | *lb.* | *oz.* | | *lb.* | *oz.* |
|---|---|---|---|---|---|
| A | 3 | 7 | G | 2 | 6 |
| D | 3 | 6 | F | 2 | 0½ |
| C | 2 | 12½ | H | 1 | 14 |
| B | 2 | 9 | E | 1 | 13 |

*1951.* Five randomized blocks were planted but no statistical differences were found. The mean yields are given in order of weight.

| | *lb.* | *oz.* | | *lb.* | *oz.* |
|---|---|---|---|---|---|
| C | 3 | 1¼ | H | 2 | 14 |
| A | 3 | 0 | D | 2 | 13¾ |
| F | 2 | 15 | B | 2 | 11½ |
| E | 2 | 14 | G | 2 | 10 |

*1952.* Forty randomized blocks were planted in a plot covering twenty drills, with each block occupying one half-drill.

As indicated by the analysis of variance below, there are highly significant differences between clones as regards yield, at the 0·1 per cent.

*Analysis of Variance of Yield (neglecting sett-weight)*

| | *d.f.* | *S. sq.* | *Mean sq.* | *Variance ratio* |
|---|---|---|---|---|
| Between half-drills (*a* and *b*) | 1 | 492·6 | 492·6 | 6·74 (1% S) |
| Between half-drills (remainder) | 38 | 2,157·4 | 56·8 | .. |
| Between clones | 7 | 2,635·9 | 376·6 | 5·15 (0·1% S) |
| Error | 273 | 19,956·7 | 73·1 | .. |
| Total | 319 | 25,242·6 | .. | .. |

level of significance. There is also a significant difference between the two adjacent plots of half-drills, *a* and *b*, each comprising twenty blocks.

On further investigation it was found that sett-weight had a small but significant effect on yield. (An increase of 1 oz. in the sett-weight corresponded to an average increase of 5·3 oz. in yield; i.e. the regression coefficient was 5·3 (±0·6).) This would to some extent affect the comparison between clones since the mean sett-weight was not the same for each clone. The following analysis of variance of yield corrected for sett-weight shows, however, that the clones still differ significantly even when sett-weight is taken into account.

*Analysis of Variance of Yield (eliminating effect of sett-weight)*

| | *d.f.* | *S. sq.* | *Mean sq.* | *Variance ratio* |
|---|---|---|---|---|
| Between clones . . . | 7 | 1,934·0 | 276·3 | 4·93 (0·1%) |
| Error . . . . . | 272 | 15,250·6 | 56·07 | .. |
| Total . . . . . | 279 | 17,184·6 | .. | .. |

The following table gives the mean yield for each clone, the numbers in the first column being the uncorrected yields and those in the second column the yields which would have been expected if the mean sett-weight for each clone had been exactly 3 oz.

*Mean Yields (oz.) per Sett*

| *Clone* | *Uncorrected yield* | *Corrected yield (for sett-weight of 3 oz.)* |
|---|---|---|
| C | 51·6 | 51·9 |
| A | 50·4 | 50·1 |
| D | 48·0 | 48·7 |
| G | 46·2 | 47·5 |
| F | 46·4 | 47·3 |
| B | 45·3 | 46·8 |
| H | 43·2 | 44·3 |
| E | 43·4 | 44·2 |
| Standard error | ±1·4 | .. |

It is clear that clones A and C are well above the general average, while E and H are well below. The expected yield from 1 acre (13,000, 3 oz. setts) for clones A and C would be 18½ tons and for E and H, 16 tons.

*Discussion.*—With regard to yield, it does not matter if differences are due to retrogressive mutations only, the normal form remaining constant, or to retrogressive and progressive mutations. Viruses also may mutate and the effects of different strains may cause differences in yields [4]. So far, however, strains of virus 'E' have not been recorded and it has been assumed that, being uniform throughout the clones, this virus has not interfered with results.

It is possible that clones react differently in various seasons and further

yield trials are necessary to study this effect. Clones A and C have maintained their yielding capacity over the 3-year period, also the range in the year of selection approximates closely the range in 1952. Too much emphasis, however, cannot be placed on the individual yields at selection or on the small yield differences in 1951. Owing to the relatively few numbers involved, the consequent absence of any statistical proof in the latter, and the random source of the former, the effect of many other factors, e.g. soil and manuring, could so influence the yield as to obscure yielding ability.

Without further work it is also impossible to state how frequently mutations affecting yields arise in potatoes. Judging from foliage mutant forms, it is unlikely that they are sufficiently frequent to permit the rapid degeneration of any high-yielding clone.

*Conclusions.*—Assuming virus 'E' has not affected the yield, the results are of some consequence.

1. High- and low-yielding clones appear to be present in King Edward and probably in other varieties.
2. The yielding capacity of clones appears to be heritable.
3. Increases in yield per acre may be possible by selection for high yield coupled with clone testing.

The investigation is being continued to determine whether clone differences are affected by season.

## REFERENCES

1. J. G. Bald, Testing and Maintenance of Potato Clones. Empire J. Expt. Agric., 1950, **18**, 95–104.
2. T. P. McIntosh, Variations in Potato Varieties. Scot. J. Agric., 1945, **25**, 125–32.
3. Anon., Clonal Selection. Potato News from the Netherlands, 1952, **2**, 1.
4. Phyllis E. M. Clinch and R. McKay, Effect of Mild Strains of Virus X on the Yield of Up-to-Date Potato. Sci. Proc. R. Dublin Soc., 1947, N.S., **24**, 189–98.

# A BACTERIAL DISEASE OF CASSAVA (*MANIHOT UTILISSIMA*) IN NYASALAND

P. O. WIEHE AND W. J. DOWSON

WITH PLATE 2

A SEVERE leaf-spot resulting in defoliation of Cassava or Manihot (*Manihot utilissima*) was first observed by one of us (P.O.W.) in Nyasaland in April 1949, and on investigation was found to be caused by a bacterium, cultures of which were sent to the Commonwealth Mycological Institute, Kew, for determination.

The disease is common in the southern province of Nyasaland where it may cause serious damage during the rainy season that lasts from December to April. Field observations indicate the existence of marked varietal susceptibility and resistance to the disease.

*The disease.*—The spots on the leaves appear as chlorotic dots and are at first yellowish and circular in outline measuring up to 2 mm. in diameter. The central portion soon turns brown, the spots enlarge, become angular and translucent, and are surrounded by a broad yellow halo (Plate 2). The veins also become discoloured dark brown and are very conspicuous when examined by transmitted light. The necrosis of the veins extends radially for 5 mm. from the angular margins of the spots, but the leaves are shed before the petioles are badly infected, so that the stems are not attacked.

Under very humid conditions, the spots coalesce causing the destruction of large areas of the lamina followed by defoliation that may be severe, and such plants appear to be more susceptible to attack by the fungus, *Botryosphaeria ribis* Gr. and Dug. which causes a die-back often extending to ground-level.

From the lower surface of infected leaves a profuse sticky substance containing bacteria exudes and dries out as yellowish glistening scales.

*Isolation of the pathogen.*—Portions of the chlorotic margin of leaf spots were cut out with sterilized scissors and were either immersed in 1:1,000 mercuric chloride and subsequently rinsed in changes of distilled water, or were rapidly flamed after dipping in 70 per cent. alcohol. The pieces were then planted on slopes of peptone-dextrose agar. Superficially identical bacterial colonies developed in eight tubes, from one of which dilution cultures were made.

*Inoculation experiments.*—With a pure culture so obtained inoculations were made on potted plants of Cassava, (1) by pricking the leaf-blade gently with a sterile needle through drops of a suspension of the bacteria in sterile water; (2) by placing drops of the bacterial suspension on both surfaces of leaves. Controls were established with sterile water.

The first sign of infection was observed 8 days after inoculation by the first method and 13 days later by the second method. Four weeks after inoculation, six inoculated leaves showed typical lesions which had spread to the secondary veins reaching as far as the leaflet midrib.

[Empire Journ. of Exper. Agric., Vol. 21, No. 82, 1953.]

Thirty-one days after inoculation the organism was re-isolated from several lesions. The control plants remain healthy.

The infection experiments showed that the disease was caused by a bacterium which gains entrance through wounds and via the stomata.

It is considered probable that dispersal of the dried exudate by wind and rain is closely associated with the dissemination of the disease.

### *Description of the Pathogen*

*Cultural characters.*—Cultures of the pathogen on nutrient (meat-infusion with yeast-extract) agar and glucose agar are pale yellow, slimy, and copious on the latter medium, and also on sterilized potato on which a characteristic pale yellow, confluent, honey-like growth develops, eventually consuming the potato without discoloration.

*Biochemical characters.*—The organism forms a considerable amount of acid in sucrose, much less in dextrose and maltose, and none in lactose when these sugars are incorporated in a peptone-free medium containing bromthymol blue as indicator, incubated at 27° C. for 28 days. No acid is formed in salicin, glycerol, or mannitol under similar conditions. Much $H_2S$ is produced (lead acetate paper suspended over peptone water) and a little nitrite is produced from nitrate in 7 days (sulphanilic acid followed by dimethyl-α-naphthylamine).

*Morphological characters.*—The organism is a short, motile, Gram-negative rod provided with a single polar flagellum, growing slowly in most media, and does not become motile until the third day.

The morphological and cultural characters together with the inability to form acid from salicin, are those of the genus Xanthomonas the species of which, with very few exceptions, are confined to a single genus of host plants.

It is therefore proposed to call this pathogen *Xanthomonas cassava* sp. nov., and it is probable that it is the cause of the similar disease in Uganda investigated by Hansford [1], who described the same leaf spotting, invasion of the petioles, and subsequent defoliation; but added that the stems were also attacked, which, however, might have been due to Botryosphaeria as mentioned above.

Hansford's inoculations were successful, but the culture he sent home for determination does not agree with the one isolated in Nyasaland. One of us (W.J.D.) determined the characters of the Uganda organism as those of a species of Bacterium, yellow in colour, having peritrichous flagella and forming acid in salicin, for which Hansford proposed the name *Bacterium cassavae*. *B. cassavae* Hansford, however, possesses exactly the same characters as *B. lathyri* (Manns and Taubenhaus) Burgwitz, now recognized as a very common and ubiquitous saprophyte constantly associated with diseased plant-tissues, particularly leaves. It seems probable, therefore, that after Hansford had demonstrated beyond any doubt that the Uganda Cassava disease was caused by a bacterial pathogen, by some error, a culture of *B. lathyri* was sent home for determination instead of a culture of the real pathogen (young colonies are very similar in appearance).

Cassava leaf infected with *Xanthomonas cassava* n.sp. photographed by *reflected* light.
(Natural size)

A wilt disease of the same host in South America has been described by Burkholder [2] who called the pathogen he found responsible, *Phytomonas manihotes*, but which is referred to in both the latest edition of Bergey [3] and in Elliott's second edition [4] as *Xanthomonas manihotis* (Arthaud-Berthet) Starr. Although it is not impossible that there may be two distinct species of Xanthomonas, one in East Africa, the other in South America on Cassava, it is most unusual to find more than one species of this bacterial genus attacking the same host. Moreover, the description of the South American pathogen as being white and probably non-motile throws some doubt on the determination. The characters as described by Burkholder are not those of a typical Xanthomonas.

*Summary.*—A severe leaf-spotting leading to defoliation of Manihot or Cassava (*Manihot utilissima*) occurs in Nyasaland and has been shown to be due to a bacterium here described, for which the name *Xanthomonas cassava* sp. nov. is proposed.

A similar disease already recorded from Uganda is probably due to the same pathogen, which was first named *Bacterium cassavae* Hansford in error.

*B. cassavae* Hansford is synonymous with *B. lathyri* (Manns and Taubenhaus) Burgwitz, a common saprophyte of necrotic plant tissues.

The wilt disease of Cassava in South America, said to be caused by *Xanthomonas manihotis* (Arthaud-Berthet) Starr is quite distinct and may not be due to a species of Xanthomonas.

## REFERENCES

1. C. G. Hansford, Ann. Rept. Plant Pathologist, Dept. Agric. Uganda, 1936, p. 47.
2. W. H. Burkholder, Phytopathology, 1942, **32**, 146.
3. Bergey, Manual of Determinative Bacteriology. 6th edition, 1948, p. 170.
4. C. Elliott, Manual of Bacterial Plant Pathogens. 2nd edition, 1951, p. 125.

(*Received September 7, 1952*)

# EDWARD HOWARD TRIPP

20 JANUARY 1874–22 JULY 1953

*It is with the deepest regret that we have to announce the death of Dr. E. H. Tripp, who has served as Secretary and Editor of this journal since its inception in 1932.*

*By training, experience, and temperament he was well fitted for this post. He began his education at Merchant Taylors' School and then in the early 1890's proceeded to the Continent to study at the Universities first of Marburg, then of Lausanne, and finally of Berlin. It was a time when German science stood in very high repute in British schools and universities and when our students always desired to study there for a period. The subjects he selected were chemistry, physics, mineralogy, and philosophy, and at the end of his course he gained his degree of Doctor of Philosophy* multa cum laude, *the highest encomium that could be given.*

*On returning to England he was in 1899 appointed Head of the Chemical Department of the Municipal Technical College, Swansea, a post he held for five years. He then transferred to the Bedford Modern School as Senior Chemistry Master and remained there till 1916. The First World War had by that time reached a terribly critical stage, and all available expert scientific help had to be mobilized to deal with urgent problems of munitions and food production. He accepted the call, worked for a time in the research laboratories of Chance & Hunt, Ltd., and then joined the Food Production Department set up by the Ministry of Agriculture under the direction of the late Sir Thomas Middleton. The Society of Chemical Industry was, however, needing a joint editor for its important journal, and in 1917 he accepted this position. His long teaching experience had given him abundant opportunities of practising the art of compact and lucid*

*expression, and this he found useful in dealing with some of the diffuse and ill-worded papers submitted to him. He had, moreover, kept up the French and German acquired in his student days on the Continent and had added Spanish and a little Italian to his list: he could therefore cope with a wide range of scientific literature.*

*In 1923 he gave up this editorship for work in the fertilizer industry, first with Organic Fertilizers Ltd., then in 1927 with Nitram Ltd., and finally in 1931 with Imperial Chemical Industries Ltd., with whom he remained associated in an active capacity till 1937 and afterwards as consultant.*

*For a number of years he had suffered much from arthritic rheumatism which more and more crippled him, but he bore it with exemplary patience and never let it interfere with his work. Unfortunately, as time went on a new trouble developed. Cancer set in, and though an operation to remove it was successful pneumonia supervened, and this he was unable to resist.*

*He gave faithful service to this journal, establishing the happiest relations with his publishers and all others concerned with it, and in spite of the difficulties arising from the wide scattering of its contributors he always succeeded in having a group of interesting papers ready for each number. He will long be remembered by those who knew him.*

JOHN RUSSELL

# THE SPACING OF NIGERIAN CACAO

T. A. RUSSELL

(*Department of Agriculture, Ibadan, Nigeria*)

To the Agricultural Officer whose knowledge of cacao was gained in Trinidad, the way of planting followed in West Africa is unorthodox and not what he has been led to consider the best practice. There is no order about the West African peasant's cacao farm and the trees seem to have been planted haphazard. Many farmers' plots have the appearance of overcrowding and the trees are tall, lanky, and poorly developed. Yet in these conditions the bulk of the world's cocoa is produced, and the observer is driven to ask himself if this way of doing things is right after all, or if the yield would not be improved by a wider spacing designed to give better development of individual trees as is common practice in the cacao plantings of the New World.

Squibbs [1], discussing Gold Coast cacao, suggests that the West African is right. 'There is reason to believe that there is no "best" planting distance for cocoa even in one locality or on one soil type. Random close planting and allowing the trees to thin themselves as they mature is probably the best practice. This is the local method.' van Hall [2] draws attention to the great differences in planting-distances used in various countries and to the controversy as to which practice is best. He suggests 12 to 17 ft. as the most usual range but refers to such close planting as 6 or 7 ft. (1,100 trees to the acre) in the Gold Coast and such wide planting as 15 by 24 ft. (121 trees to the acre) in Surinam. He is careful to point out that the most suitable distance will depend upon the conditions in which the cacao is grown. Despite the wide divergence of opinion about the best spacing to adopt, few attempts at spacing-trials seem to have been made. van Hall [2] describes a non-statistical planting at River Estate, Trinidad, in which four plots were planted with cacao at 12-, 14-, 16-, and 18-ft. spacing. In this experiment the 12-ft. distance gave highest yield per acre for the first 6 years of production but was then surpassed by the 14-ft. spacing.

In Nigeria a field trial employing three planting-distances was undertaken in 1934, and a second one with seven spacings 8 years later, and the writer has been in charge of these plantings. The purpose of this paper is to summarize results of these two experiments and to record some observations on the spacing of cacao in peasant farms in the main cacao area of western Nigeria.

## *The First Spacing Trial, 1934*

In this trial, planted on the Government Cacao Farm, 12 miles south of Ibadan, three spacings were adopted, 8 by 8 ft., 12 by 12 ft., and 15 by 15 ft., or 675, 300, and 192 trees to the acre-plot.

Ibadan is rather more than 7° N. of the Equator in the vegetative zone now known as Dry Forest. The annual rainfall is commonly about

[Empire Journ. of Exper. Agric., Vol. 21, No. 83, 1953.]

47 in., and the year has a marked dry season from November to March when little or no rain may fall.

The land used was previously under secondary forest which was clear-felled to allow of planting of Gliricidia shade in 1932 and of banana plants early the next year. Cacao seedlings were transplanted into the field during the rainy season of 1934. The planting material was selfed seedlings of Trinitario trees, with characters not far removed from Amelonado. Their original selection has been described by Voelcker [3].

The plot-size was 1 acre and each spacing occurred once in each of six blocks, the arrangement of the three treatments within each block being randomized. There were therefore eighteen 1-acre plots. Trees of Albizzia and Erythrina were planted to give a light shade over the cacao.

Very heavy loss of seedlings occurred in the first dry season, and it was not until 1937 that the plots were well supplied. Subsequent growth was irregular in different parts of the field, and in two blocks especially the cacao failed badly, on account of a hard-pan which was not discovered until later. The results described are based on the four blocks in which more satisfactory growth was made. A small number of pods was harvested in 1938 and regular 3-weekly harvesting and yield-recording was started in the crop season of 1940–1.

Table 1 gives the mean yield of pods per acre and per tree, also the mean weight of wet cacao from 100 pods in respect of the three spacings during the 2-year period April 1941 to March 1943 (the eighth and ninth years after original planting), and again from April 1950 to March 1952 (the seventeenth and eighteenth years after planting). The production of 2 years is taken instead of an annual yield because figures from other plots have indicated a biennial fluctuation in yield, trees which bore heavily one year giving a reduced yield the next.

TABLE 1: *Production of Cacao in the Eighth and Ninth Years combined and the Seventeenth and Eighteenth years after Planting*

| | *April 1941–March 1943* | | | *April 1950–March 1952* | | |
|---|---|---|---|---|---|---|
| *Column 1* | *2* | *3* | *4* | *5* | *6* | *7* |
| *No. of trees per acre* | *Mean no. of pods per acre* | *Mean no. of pods per tree* | *Mean wt. of wet cacao per 100 pods (lb.)* | *Mean no. of pods per acre* | *Mean no. of pods per tree* | *Mean wt. of wet cacao per 100 pods (lb.)* |
| 675 | 9,045 | 13·40 | 17·92 | 11,229 | 16·64 | 18·11 |
| 300 | 1,897 | 6·32 | 18·30 | 6,321 | 21·07 | 19·25 |
| 192 | 1,910 | 9·95 | 18·93 | 5,232 | 27·25 | 19·52 |
| Difference required for significance | | Difference not significant | Difference not significant | | | Difference not significant |
| at P = 0·01 | 6,125 | | | 4,747 | 8·99 | |
| at P = 0·05 | 4,043 | | | 3,133 | 5·93 | |

*Note*: the figures in columns 4 and 7 are based on disease-free pods only, whereas in counting the number of pods per acre and per tree all pods, healthy and diseased, were reckoned.

In column 2 it is seen that in the eighth and ninth years after original planting the mean yield of pods from the closer-planted plots was much greater than those from the two wider spacings, the difference being highly significant statistically. The yield of pods per tree (column 3) shows no clear effect. The closest spacing gives highest yield per tree due possibly to easier establishment at close spacing, but there is wide variation within the plots and no great weight can be placed on this difference.

From column 5 it is evident that the close spacing is still giving highest yield per acre 17 and 18 years after planting, its superiority over the two wider spacings being still highly significant. Nevertheless the yield of the close planting has not increased very greatly in 9 years of growth whereas both wider plantings show a notable increase in production in that time. The mean yield per tree (col. 6) shows individual tree production to be much greater in the wider spacings.

The figures in columns 4 and 7 suggest that the more space a tree has the larger are the pods, but the differences are not sufficiently large and consistent to be significant.

In this trial it has been necessary to assess the productivity of the trees by number of pods rather than by weight of cacao produced, owing to the destruction of many of the pods by Phytophthora pod-rot before the beans were ripe. This loss, which was negligible in 1941–3, increased year by year and reached serious proportions in the season 1951–2, being heaviest in the plots producing the greatest number of pods per acre. This led to the extraordinary result that the plots producing most pods gave the lowest yield of good cacao beans. That greater loss in the close-planted plots is not an invariable feature will be seen from Table 2 in which are shown for several seasons the number of pods infected by Phytophthora expressed as a percentage of the total number of pods produced.

TABLE 2. *Percentage Incidence of Black-pod at Different Spacings*

| *No. of trees per acre* | *No. of infected pods expressed as percentage of pods produced* | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1945/6 | 1946/7 | 1947/8 | 1948/9 | 1949/50 | 1950/1 | 1951/2 |
| 675 | 3·6 | 11·6 | 16·8 | 38·5 | 41·6 | 43·0 | 73·9 |
| 300 | 2·8 | 11·8 | 9·2 | 31·5 | 39·2 | 48·2 | 47·4 |
| 192 | 2·3 | 10·0 | 5·6 | 31·8 | 34·6 | 44·8 | 30·2 |

These figures clearly show the mounting damage caused by pod-rot with increasing age of the plot. Although there seems a tendency for greater loss to be caused in the densest plots, this is not the case in every year, and further evidence would seem necessary before any firm conclusion is reached. An investigation is being made by Mr. C. A. Thorold on the black-pod disease of cacao in Nigeria which may shed more light on the effect of tree-spacing on the incidence of disease.

### *The Second Spacing Trial, 1942*

A second trial on a more ambitious scale was planted on the same farm in 1942 in which seven distances were used: 5 × 5 ft., 1,742 trees; 6 × 6 ft., 1,210 trees; 6 × 7½ ft., 968 trees; 7½ × 7½ ft., 772 trees; 10 × 10 ft., 435 trees; 12 × 12 ft., 302 trees; 15 × 15 ft., 193 trees.

The treatments were planted in the form of a latin square, the plot-size being 60 ft. square or approximately 1/12 acre with, in addition, a guard-row of non-experimental trees round each plot. The planting-material was partly Amelonado seedlings typical of the farmers' cacao in the district, and partly selfed seedlings of a Trinitario selection known as T 38 resembling Amelonado in most characters, the two varieties being evenly distributed in each plot. In this planting the soil was tested by the Agricultural Chemist before work was started. Soil-pits were dug at intervals and the field was stated to be uniformly suitable. The land was previously under poor secondary forest and this was clear-felled to allow the planting of Gliricidia and banana shade before the cacao went in. No tall overhead shade was grown. Establishment of cacao was reasonably good and a closed canopy was soon formed in the near spacings. A few pods were produced in 1946 and regular harvesting was done from 1947 onwards, the sixth year from planting.

The difference in appearance between close-spaced and wide-spaced plots became very marked. In the closest plots, the trees stood up as straight poles almost unbranched to the top, where a small umbrella of branches and foliage was formed. The early closing of the canopy suppressed weeds and the ground was bare and covered with a thick carpet of dry cacao leaves. Pods were almost confined to the trunks. In the wide-planted plots the trees had the typical storied shape of cacao uninhibited in its growth. Low branching occurred and a good proportion of the pods were borne on the lateral branches. The trees were slow in forming a canopy and indeed, 10 years after planting, the trees spaced at 15 ft. had not nearly met. As a result the ground was covered with other vegetation which had to be cutlassed from time to time. The intermediate spacings, such as 7½ ft., permitted some low branching and the closing of the canopy after several years' growth.

Table 3 gives the number of pods obtained in the first 5 years of production, the sixth to tenth years after planting. For the tenth year are shown the mean yield of pods per tree and weight of beans per pod at the different spacings.

Columns 3 and 4 show that the closest planting produced more pods than any other spacing in the first 2 years of cropping. For the next two years the second spacing went ahead, but this in turn gave way to the third in the fifth year of yield-recording, that is the tenth year after planting (column 7). In this year indeed the difference between the yields of the first four spacings showed no significance at a level of $P = 0{\cdot}05$. The fourth closest planting at 7½-ft. spacing increased greatly in yield in this year and may be expected to compete for first place in the near future.

The mean yield per tree in the tenth year after planting (column 9) was greatest in the third and fourth closest planted plots, the increase

over most of the other spacings being statistically significant. It was thought that in this respect the two kinds of cacao contained in the field might behave differently, but no difference of any significance could be observed from the yield figures. No serious loss from pod-rot occurred up to the tenth year.

TABLE 3. *Number of Pods produced per acre by Cacao at Different Spacings in the Sixth to Tenth Years after planting and the Number of Pods per Hundred Trees and Weight of Wet Cacao per 100 Pods in the Tenth Year*

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|
| | | *No. of pods produced per acre* | | | | | | *10th year* | |
| *Spacing* | *No. of trees per acre* | *Year 6* | *Year 7* | *Year 8* | *Year 9* | *Year 10* | *Total 5 years* | *Mean No. of pods per tree* | *Mean wt. of wet cacao per 100 pods (lb.)* |
| A | 1,742 | 85 | 1,249 | 823 | 2,320 | 4,171 | 8,648 | 2·39 | 19·9 |
| B | 1,210 | 40 | 878 | 1,203 | 2,809 | 4,493 | 9,423 | 3·71 | 19·4 |
| C | 968 | 76 | 888 | 797 | 2,426 | 5,196 | 9,383 | 5·37 | 20·2 |
| D | 774 | 21 | 300 | 162 | 1,215 | 4,009 | 5,707 | 5·18 | 19·8 |
| E | 435 | 5 | 156 | 43 | 498 | 696 | 1,398 | 1·60 | 20·3 |
| F | 302 | 36 | 156 | 22 | 289 | 817 | 1,320 | 2.70 | 20·9 |
| G | 197 | 19 | 71 | 9 | 156 | 415 | 670 | 2·11 | 21·7 |
| Total | | 282 | 3,698 | 3,059 | 9,713 | 19,797 | 36,549 | (*a*) | |

(*a*) In column 9 a difference of 2·19 is significant at P = 0·05 level.
" " " " 2·94 " " P = 0·01 "

The size of pod as measured by mean weight of wet beans per 100 pods showed no significant difference in the various spacings, though column 10 suggests a tendency towards larger pod-size as the trees become more widely spaced.

The three widest plantings remained far behind in yield per plot throughout the first 5 years of bearing and they were also inferior in yield per tree. The maintenance of these plots was more troublesome than that of the close plantings. It proved difficult to have adequate shading in the dry season without excess in the rains, and continual control of shade and of competing bush-growth was necessary. The same trouble was not experienced with the closer plantings where the cacao soon made its own canopy and shade-control consisted merely in removal of bananas and reduction of Gliricidia where these interfered with the cacao. Unskilful management of the shade undoubtedly impaired the growth of the wide-planted cacao and its yield in this experiment. But it is unlikely that the ordinary farmer would have managed it any more adroitly, and the difficulty of manipulating the shade has to be reckoned as a disadvantage attendant on the wider spacings.

### *Observations on Peasant Farms*

The results of field-trials such as have been described have the limitation that they may be strictly applicable only to the conditions prevailing on the site of the experiment, such as nature of the soil, distribution of rainfall, and presence or absence of shade.

Another possible approach is to study farmers' plots as they exist in all their variability throughout the cacao areas and to attempt to derive some general connexion between yield and spacing. This method calls for no less effort since accurate records have to be maintained on a number of farms over several years. Information of this kind is not yet available for many farms. Detailed records have, however, been made on a group of peasant farms at Agodi, about 3 miles north-east of Ibadan, which make a continuous block of cacao nearly 10 acres in extent on land acquired by Government in 1938. Systematic yield-recording was started in 1943 and has been continued since then, harvesting being done at 3-weekly intervals throughout the year.

The soil in the greater part of the farm is a brown loamy clay overlying a deep layer of red clay. It is considered suitable for permanent cultivation of cacao, having a good moisture-retaining capacity and adequate aeration, sufficient depth, and a fair content of nutrients. In one corner of the farm, however, there is inferior soil consisting of a sandy loam overlying sand, which, though planted with cacao, is hardly considered to be suitable. The cacao is of Amelonado type universally grown by farmers in the Ibadan district and is lightly shaded by taller trees, mostly *Albizzia zygia* and *Pithecolobium Saman*.

Examined in detail, this 10-acre block of cacao proved to be made up of no less than twenty-seven plots of varying shapes and sizes, some planted by different farmers, others by the same farmers but at different times, and showing a wide range of tree densities. Close planting was common to most of the plots, the mean density for the whole farm (which includes some small blank spaces without cacao) being 679 trees to the acre. In three plots the trees were as thick as 1,348, 1,278, and 1,096 to the acre. All of these were young plots not more than 12 years old at the time of counting. The oldest plots over 20 years of age did not include more than 500 trees per acre.

In a few of the plots, including some of the younger ones, the relatively open spacing was accompanied by a spreading habit of the trees from the base, suggesting that they had been widely planted from the start. In none of the plots could be seen any attempt at regular planting in rows. The distribution of trees is described and illustrated in a paper on experimental plot-size which made use of data from this farm [4].

TABLE 4. *Yield of Pods from Cacao at Different Spacings during a 6-year Period*

| *Plot* | *No. of trees per acre* | *Mean yield of pods per 1/100 acre* | *Mean yield of pods per tree* |
|---|---|---|---|
| U | 426 | 423 | 99 |
| V | 686 | 516 | 75 |
| E | 802 | 654 | 82 |
| G | 806 | 652 | 81 |
| B | 818 | 624 | 76 |
| K | 821 | 669 | 82 |
| P | 1,096 | 640 | 58 |

Seven plots in good condition and believed to be about the same age were chosen for comparison. In Table 4 are shown the mean yields of pods per unit of area (1/100 acre) and per tree during a period of 6 years when the trees were approximately 13 to 18 years old.

These figures show almost equal yields being given by plots with from 800 to 1,100 trees, the lower yield per tree in the closest spacing being balanced by the greater number of trees. Below a certain density, about 700 trees to the acre, the yield per acre falls off. These findings, which by themselves cannot carry any great weight, nevertheless bear out the results of the second spacing trial.

### *The Farmer's Planting Method*

Haphazard though the farmer's cacao may appear, it is not planted entirely without method. Normally the bush is cleared by cutlassing and burning of the undergrowth and by killing the taller trees with fire. The surface-soil is then scraped up with the hand-hoe into small hills that vary in size and distance but are often roughly 4 or 5 ft. apart. Food-crops are planted in these hills, yams during the dry season or maize with the first showers, and, after the rains have set in, cacao seeds are sown four or five in a hole in the hollow between four hills. The original planting-distance therefore tends to be about 5 ft.

Loss of the young seedlings is usually heavy. The germinating seed is relished by many small animals of the bush and the seedlings which survive this attack, while still only a foot or so high, have to meet their first dry season, a rainless period extending sometimes for 3½ months. The losses to be expected in planting cacao from seed in the Ibadan district may be illustrated by a test planting made at Agodi Farm.

Cacao was sown during the wet season of 1948 on nearly ¼ acre of land previously under secondary bush, 442 holes being planted and 3 seeds sown per hole. Germination was good but almost 70 per cent. of the seedlings died in the first dry season. Vacant stands were supplied in the rains of 1949 and again each year until 1952, when 331 of the stands or 75 per cent. had been successfully established. The difficulty of establishing cacao in these conditions serves to explain the great variations that occur in the density of native farms. The closeness of planting reflects the farmer's anxious care to obtain establishment and the stand of trees finally established is a measure either of the fortune of the seedlings in escaping damage or of the farmer's persistence in replanting until the gaps are filled.

The established cacao trees are still subject to continual hazard. Termites will destroy young trees and also older trees that become weakened or damaged in any way. Antelopes may bark a tree or a large forest tree may crash down on the cacao.

On the Agodi Farm, at the end of 10 years, 10 per cent. of the trees have died, the cacao varying from 18 to 32 years of age. Highest percentage loss is found in some plots which are planted in the poorer soil at one end of the farm.

*Conclusions*

All the results quoted in this paper stress the value of close planting under the conditions here prevailing. In our experience the densest planting gives the easiest establishment of a cacao farm. A closed canopy is formed by the young trees at an early age and the difficulties of controlling shade efficiently at the different seasons of the year are avoided. The results also show that close spacing is desirable for high early yield.

The maintenance of a closed canopy is the most important factor in the life of a Nigerian cacao farm. The conditions in the main cacao area include a wet season of heavy rains, an extreme dry season, and the virtual absence of large trees overshadowing the cacao. In these conditions the breakdown of the canopy spells the end of the cacao farm. The initial cause may be swollen-shoot disease or attack by capsid, extreme drought or destruction of the branches by mistletoe, but the progress of decline follows much the same course. The trees are defoliated, the ground insufficiently protected. The rains pour down and ruin the soil texture, the sun blazes on it and bakes it hard, the humus and leaf-litter are gone. The trees flush frequently and feebly, the leaves are reduced in size. Grass creeps into the plot and the cacao trees, stunted and derelict, die. The presence of tall shading trees may prevent or delay this course of decay, but of equal importance is a close and even spacing of the cacao so that a dense complete canopy is formed by the mingling of the cacao branches.

Figures from the second yield-trial and from Agodi Farm show that, within a certain range of densities, the yield per acre is not much affected by planting-distances. Thus under the conditions of the plantings the same yield was given by 800 as by 1,100 trees to the acre. At wider spacing the yield per acre declined. There would seem some advantage in aiming at the higher density and closest spacing within this range in the hope that, as the trees are gradually reduced by mischance during the life of the farm, the yield per acre may nevertheless be maintained.

There remains the question of close-spacing and disease-control. The dense planting of cacao may be expected to assist the rapid spread of swollen-shoot disease within a farm since the wingless vector, the mealybug, is able to pass from tree to tree along the branches that are in contact. The spread of virus between neighbouring trees may be greatly retarded if the trees are not touching, as happens, for instance, with young plantings. Since, however, a closed canopy is regarded as essential, the contact of neighbouring trees cannot be avoided and there is no information to show how greatly the closeness of the contact trees affects the rate of spread.

The figures from the first spacing-trial suggested that percentage loss from Phytophthora pod-rot was greatest in the high-yielding plots at near planting-distance, though this result was not sufficiently straightforward to be strongly affirmed. It is obvious that the disease cannot be greatly reduced by wider spacing and that other means of control, such

as fungicidal spraying, have to be employed if heavy loss is to be prevented. It might be thought that, if spraying is to be done, wideness of spacing would be necessary to allow easy access to the trees, but in the closer plantings the growth of lateral branches is discouraged and it becomes an easy matter to pass between the trees. Of greater importance is the planting of the trees in rows so that the equipment can move rapidly and freely.

From several points of view therefore the close planting of cacao, by which is meant a spacing of 6½ ft. to 8 ft. (800 to 1,100 trees per acre) is advantageous in the conditions in which this work has been done. The use of a more vigorous kind of cacao, higher soil fertility, or a more favourable climate leading to the growth of large trees demanding more space, might alter these conclusions, but it is believed that they are applicable to the Amelonado cacao growing in the main producing area of the Western Provinces from which the bulk of Nigeria's cocoa comes.

*Acknowledgements.* The experiments here described are mainly the work of others and I have to express acknowledgements to my predecessors, Mr. O. J. Voelcker, who laid down the trials, and Messrs. J. West and G. K. G. Campbell who carried them on. Amongst the African Assistants who supervised the husbandry and kept the records Messrs. M. L. Adegun, A. A. Osinowo, T. Quarcoo, and J. K. Olurin deserve mention. I am indebted to Messrs. C. A. Thorold and J. H. Gisborne for suggested amendments to the paper, and to the Inspector-General of Agriculture, Nigeria, for permission to publish these results.

## *Summary*

1. Results are given of field-trials to determine the most suitable planting-distance for cacao in the Ibadan district of Nigeria. Observations in the same area on farmers' cacao planted at different spacings are described.

2. It is concluded that under the prevailing conditions close planting of trees at 6½ to 8 ft. apart is advantageous. At this spacing good establishment and high early yield are assisted.

## REFERENCES

1. F. L. Squibbs, Uniformity Trial on Established Cocoa. Report on Central Cocoa Research Station, Tafo, 1938–42. Government Printer, Accra, Gold Coast, 1943, p. 6.
2. C. J. J. van Hall, Cacao. Macmillan & Co., London, 2nd edition, 1932.
3. O. J. Voelcker, Initial Cacao Selection in Nigeria. Eleventh Bulletin of the Agricultural Department, Nigeria. Government Printer, Lagos, 1936, p. 45.
4. S. C. Pearce and J. M. S. Thom. A Study of Plot-size with Nigerian Estate Cacao. Hort. Sci., 1951, **26**, 261.

(*Received March 20, 1953*)

# CLIMATOLOGICAL RESEARCH ON ANIMAL HUSBANDRY AND ITS SIGNIFICANCE IN THE DEVELOPMENT OF BEEF-CATTLE PRODUCTION IN COLONIAL TERRITORIES

JAN C. BONSMA[1] WITH J. VAN MARLE[2] AND J. H. HOFMEYR[2]

WITH PLATES 3, 4, 5, 6, 7

DURING recent years countries such as Great Britain, Spain, Portugal, and Belgium, which need to encourage emigration in order to alleviate their over-population, have shown great interest in the development of their tropical and sub-tropical colonies. If the developmental policies are to be successful, it will be necessary for the colonies to provide not only ample food and income for their new settlers, but also export surpluses of food and raw materials.

Many of the colonial territories in the southern hemisphere have a semi-arid, sub-tropical climate; such areas are pre-eminently suitable for livestock farming, especially ranching. Past experiences have proved beyond doubt that to make livestock farming a success in any particular area a thorough knowledge of that environment and the adaptability of the livestock are essential.

That many of the types of livestock originating in the northern hemisphere do not thrive in the tropical and sub-tropical environments can no longer be denied. So much has been published authoritatively during the past decade or two on the degeneration of the British beef-breeds of cattle in the semi-arid sub-tropics that it is hardly necessary to quote extensively from the literature to prove this. Of greater importance is the need to indicate how these problems of degeneration can be overcome.

Of recent years South Africa, in common with many other countries and colonial territories, has shown great interest in the improvement of the indigenous breeds and types of cattle. A committee was appointed by the Secretary of Agriculture towards the end of 1947 'to make a survey of the nature and numbers of indigenous stock in this country and to report upon the desirability and means of preserving this stock'. The first report by this committee, *N'guni-cattle: Report on Indigenous Cattle in South Africa*, has recently been published. It is hoped that many other countries and colonial territories which have hitherto not given this aspect of their animal-husbandry industry the necessary attention will, in the near future, take steps to preserve and improve their indigenous livestock.

In order to select and improve the indigenous breeds and types of livestock efficiently, it is necessary to study their reactions to specific environmental stimuli. Physiological processes are correlated primarily

[1] Principal Professional Officer, Animal Husbandry Research.
[2] Research Officers, Mara Research Station, Department of Agriculture, Union of South Africa.

[Empire Journ. of Exper. Agric., Vol. 21, No. 83, 1953.]

or secondarily with environmental fluctuations; not only is energy for life derived from the environment but rates of growth, development, fertility, and mortality all bear relationship to certain characteristics of the habitat. Behaviour patterns of animals are, therefore, in large measure responses to environmental stimuli. Since the distribution of plants and animals is determined by variations in environmental stimuli and conditions, it has acted as a selective agent in determining the survival of particular types and breeds of livestock in specific areas.

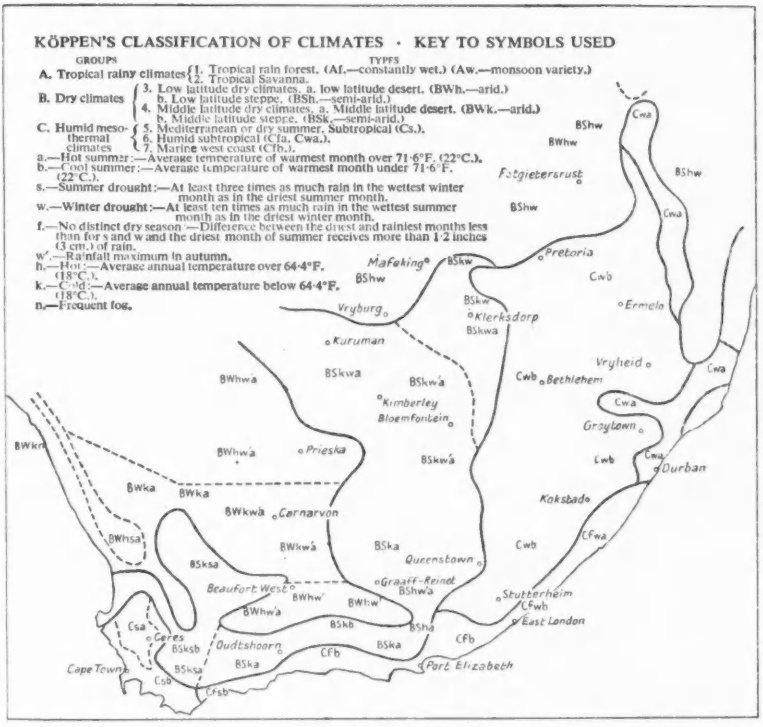



FIG. 1

Ecological research on animal husbandry now in progress at the Mara and Messina research stations has as its object the determination of the interaction between types of cattle and their environment (both the physical and the biotic), and emphasizes interspecial as well as intraspecial relationships. Precise observations on the reactions and behaviour of types and breeds of livestock in their physical and biotic environment make a useful contribution to the mass of essential ecological information required to ensure the establishment of different types and breeds of cattle in the appropriate environment.

Two aspects of animal-husbandry ecology to be constantly borne in mind are that both a proper bearer of heredity and a suitable environment are necessary for development. Due attention must also be given to plants growing in a particular region if only because the environment in which animals are sustained is largely conditioned and controlled by the nature of the vegetation. That is why Köppen's classification of world climates, which is based on temperature, humidity or rainfall, and

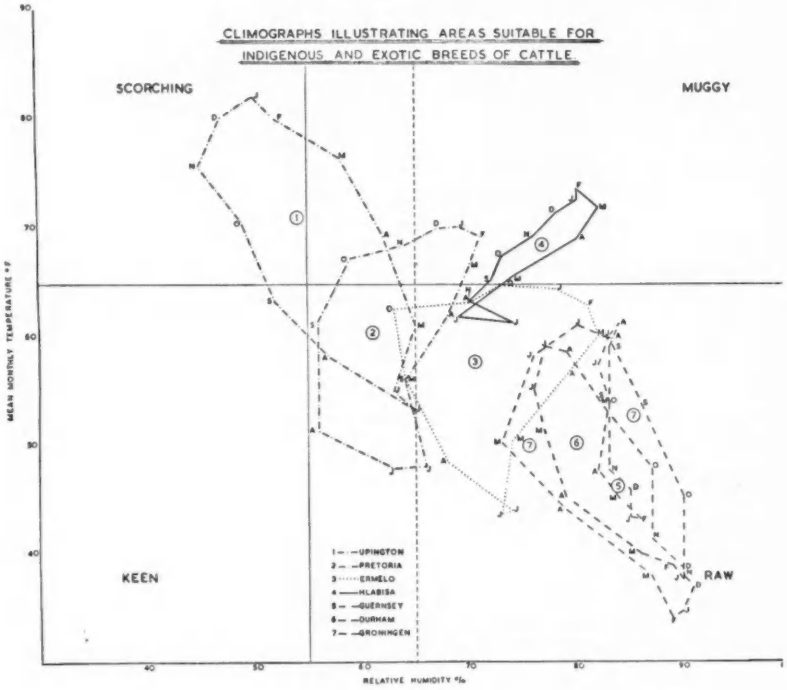



FIG. 2

vegetation types, is so useful in the regionalization of animal husbandry (see Köppen's map, Fig. 1).

Köppen's classification of climates[1] is very useful from the point of view of animal-husbandry regionalization because it takes climate and vegetation into consideration.

The BShw (hot steppe areas of average annual temperature +65° F.) and BSkw (cold steppe areas of average annual temperature −65° F.) regions are suitable for ranching. BSkw is a transitional area where livestock fattening can take place. BWhw and BWkw areas are suitable for extensive production of woolled sheep.

[1] For Köppen's classification of world climates see *An Introduction to Weather and Climate* by Glenn T. Trewartha, appendix A, plate ii.

The Cwb region is suitable for crop production and intensive livestock production, especially milk production.

Csa and Csb regions are suitable for viticulture, deciduous fruit, wheat, &c., and intensive dairy production.

Cwa regions are suitable for tropical and sub-tropical crop- and fruit-production and extensive indigenous livestock production.—*Bos indicus* types (Sanga).

In previous papers on adaptability of breeds of livestock the senior author has drawn attention to the reaction or response of individuals, types and breeds of cattle, to temperature, radiation, and other physical factors. In this paper an attempt is made to discuss in greater detail the interaction between the animal and its nutritional environment as influenced by climatological factors. In other words, whereas toleration physiology has been discussed, in previous papers, the present contribution is concerned with response physiology (see Plates 3, 4). The line between them is not necessarily sharp, nor are they mutually exclusive.

The British and European breeds of cattle (*Bos taurus*) were evolved in a relatively cold and humid climate ('raw' in map). The *Bos indicus* (Zebu) types of cattle had their origin and evolution in hot and dry (scorching) and hot and humid (muggy) climates.

The relationship between the average monthly atmospheric temperature and relative humidity of various climographic regions in which livestock are maintained is illustrated in Fig. 2.

It is considered that cattle are adaptable to areas where not more than six points of the climograph fall outside the climographic area in which the breed had its origin and evolution. 'Scorching' connotes suitable for Africander cattle (*Bos indicus*); 'muggy', suitable for N'guni (Sanga) types of cattle (*Bos indicus*); 'raw', suitable for British and European beef and dairy breeds of cattle (*Bos taurus*).

Fig. 3 indicates the relationship between altitude and average annual atmospheric temperature. Degeneration of the exotic breeds of cattle very seldom occurs at altitudes above 3,500 ft. Adaptability from a climatological point of view becomes difficult for exotic breeds of cattle at average annual temperatures above 65° F.

Through this research work on toleration physiology it has become possible to predict with reasonable accuracy the reaction of certain types and breeds of cattle in a particular environment. The end-responses that were studied, and on which data are presented, are population growth and decline, i.e. fecundity, fertility and rate of development, differential resistance to disease, and mortality. The audited figures in Table 1, obtained from ranches on which accurate data were kept, will clearly illustrate how lack of adaptability in a breed of livestock to a particular environment results in slow growth, low fertility, and high mortality. The Mara Research Station figures are included for comparison.

Dr. John Hammond has often stated that in sub-tropical and tropical semi-arid environments it is better to farm with less improved breeds, because these animals are adaptable and maintain themselves better

under poor nutritional conditions. The figures prove conclusively not only that the average calving percentage in the unadapted breeds is low but that the calf mortality is high.

On ranch C (Table 1), during the period 1946–50, 6,858 head of cattle died, of which 5,131 or 74·8 per cent. of the deaths occurred from September to January. During September and October the grazing is poor and as the unadapted cattle cannot range with ease they die as a result of starvation. From December to February the cattle in poor

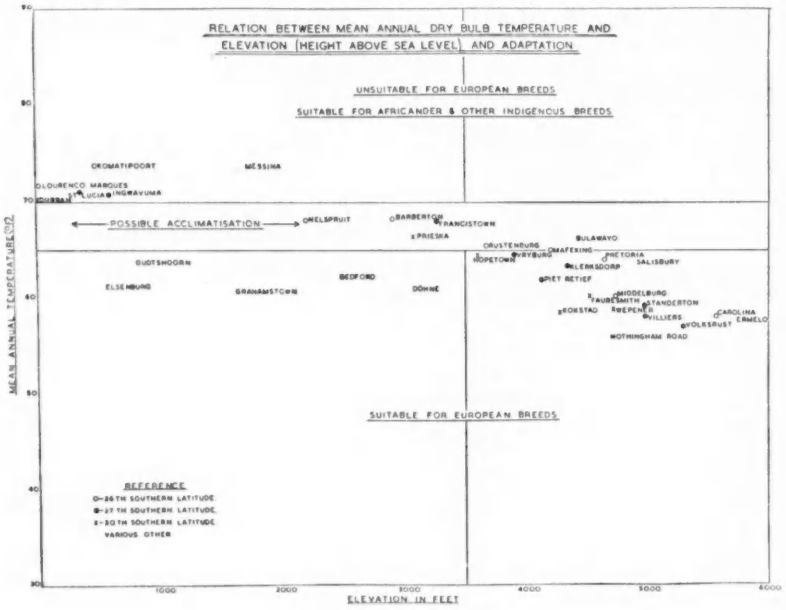



FIG. 3

condition lack heat-tolerance and resistance to tickborne disease, with the result that they readily succumb.

The research work carried out at the Mara and Messina stations lends itself to ecological interpretations because of the large numbers of cattle involved. In 1948 different types and breeds of cattle were transferred from the Mara to the Messina research station (a poorer environment, as indicated in Table 2).

The weight changes that have taken place in different types and groups of cattle which have been transferred from Mara to Messina are shown in Table 3.

Table 4 indicates the maximum average weight attained by mature cattle of the same breeding in the different types and breeds at Mara and Messina. Cattle 6 years and older are considered to be mature.

TABLE 1. *Calving Percentages and Mortality Rates on Cattle Ranches*

| *Ranch*[1] | *Locality* | *Altitude (ft.)* | *Average annual temp. (° F.)* | *Average annual rainfall (in.)* | *Breed of cattle* | *Average no. of breeding cows* | *Average % calf crop* | *Calf mortality %* |
|---|---|---|---|---|---|---|---|---|
| A | Long. E. 26° 53′ Lat. S. 24° 21′ | 2,800 | 69° | 16·2 | Herefords | 1,477 for 22 years | 39 | 18 |
| B | Long. E. 28° 21′ Lat. S. 24° 56′ | 3,650 | 65·6° | 24·1 | Aberdeen Angus | 3,143 for 5 years | 56 | 23 |
| C | Long. E. 29° 45′ Lat. S. 20° 45′ | 4,500 | 65° | 24·6 | Sussex | 17,400 for 20 years | 55 | 14 |
| Mara | Long. E. 29° 34′ Lat. S. 23° 09′ | 3,000 | 67·2° | 16·5 | Adaptable types | 416 for 6 years | 83·53 | 10·59 |

[1] At the request of the owners or directors the names of the ranches have been withheld.

TABLE 2. *Effect of transferring Cattle from the Mara to the Messina Research Station*

| *Research station* | *Location* | *Altitude (ft.)* | *Average ann. temp. (° F.)* | *Average ann. rainfall (in.)* | *Carrying capacity: cattle per acre (approx.)* |
|---|---|---|---|---|---|
| Mara . | Long. E. 29° 34′ Lat. S. 23° 09′ | 3,000 | 67·2 | 16·5 | 1 : 20 |
| Messina . | Long. E. 29° 54′ Lat. S. 22° 16′ | 1,700 | 71·7 | 12·6 | 1 : 50 |

It is evident from Tables 3 and 4 that the more adaptable, less improved, indigenous breed of cattle—namely the Africander—suffered less in the poorer environment than the more improved, exotic breeds. Table 4, giving the maximum mature weight of these different types and breeds of cattle, clearly indicates that the more adaptable breed can, under poor environmental conditions, give better expression to its genetic potentialities than can the exotic beef-breeds.

The data reveal that the factor limiting the adaptability of cattle in this environment is climate rather than feed, because the cross-bred cattle—although large and heavy and therefore demanding high maintenance

TABLE 3. *Weight Changes of Cattle on Transference from Mara to Messina*

| *Research station* | *Breed or type of cattle transferred* | *No. of animals in group* | *Average wt. when transferred 17/11/48 (lb.)* | *Average weight July 1952 (lb.)* | *Percentage difference in weight* | *Average age in months* |
|---|---|---|---|---|---|---|
| Retained at Mara | Hereford | 45 | 505·4 | 1,156 | 23·5 | 54 |
| Transferred to Messina | Hereford | 33 | .. | 884 | | |
| Hereford × Africander retained at Mara | Hereford | 18 | 634·1 | 1,196 | 5·7 | 54 |
| Transferred to Messina | Africander | 27 | .. | 1,128 | | |
| Shorthorn × Africander retained at Mara | Shorthorn | 66 | 616·7 | 1,115 | 5·4 | 54 |
| Transferred to Messina | Africander | 24 | .. | 1,056 | | |
| Mara[1] | Africander | 9 | .. | 760 | 1 | 27 |
| Messina[1] | Africander | 9 | .. | 752 | | |

[1] Cattle born at Mara and Messina—not transferred.

TABLE 4. *Maximum Mature Weights of Three Types and Breeds of Cattle*

| *Breed or type* | *Research station* | *Age mature over 6 years* | *No. in group* | *Maximum average weight (lb.)* | *Difference in weight Mara-Messina (lb.)* | *Weight of Messina cattle as % of mature Mara weight.* |
|---|---|---|---|---|---|---|
| Hereford | Mara | Mature | 62 | 1,181 | 211 | 82 |
| Hereford | Messina | | 34 | 971 | | |
| Cross-bred | Mara | Mature | 108 | 1,289 | 173 | 87 |
| Afric. × Exotic | Messina | | 51 | 1,117 | | |
| Africander | Mara | Mature | 152 | 1,230 | 95 | 92 |
| Africander | Messina | | 22 | 1,135 | | |
| Average | Mara | Mature | 322 | 1,240 | 166 | 87 |
| | Messina | | 107 | 1,074 | | |

requirements—thrive well, since they are adaptable and are also very efficient utilizers of feed.

Whereas under the poorer nutritional and drastic climatic conditions pertaining at Messina the Africanders are on an average 18 lb. heavier than the cross-breds; at Mara, where the climatic and nutritional conditions are better, the cross-breds attain an average weight 59 lb. heavier than the Africanders. Thus under the Mara conditions the cross-bred cattle do better with respect to efficiency of feed-utilization than the Africanders, since the dominant characteristic of efficiency of feed-utilization has been inherited from the exotic beef breed, whilst the adaptability characteristics such as thick hide, smooth-coatedness, high heat-tolerance coefficient have been inherited as dominant characteristics from the Africander breed.

These factors enable the cross-bred cattle to fend for themselves under adverse climatological conditions, where as a result of the lack of grazing it is difficult to get enough feed. To obtain adequate feed the animal is subjected to severe physical exertion, so that the animal not capable of dissipating large amounts of waste energy becomes hyperthermic and will not walk farther in search of feed. Self-preservation is the paramount instinct in animal behaviour, and if the animal's existence is endangered as a result of heat, the first shady bush or tree is selected to protect it from direct impingement of the sun's rays. Thus it is found that the unadapted bull will stand in the shade and will not serve cows on heat, nor will it go out grazing on hot days since its existence is endangered as a result of high atmospheric temperatures (Graphs 1 and 2). During periods of drought when feed becomes really scarce, it requires more physical exertion on the part of the heavier animal to obtain enough feed for maintenance requirements. This results in the animals with the poorest adaptability losing most weight and having by far the lowest fertility.

The average calving percentages and the fluctuations in weight of mature cows, i.e. cows over 6 years of age, of different types and breeds of cattle at Messina and Mara research stations are shown in Table 5.

During the drought year 1952 the exotic cattle lost on a percentage basis less weight than the Africanders and N'guni cattle, for two reasons. First, they had an appreciably lower calving percentage, and secondly, from a management point of view, it was found advisable during a severe drought to place the exotic beef-cattle as well as the cross-breds in the best camps where the least effort is required to reach the watering facilities.

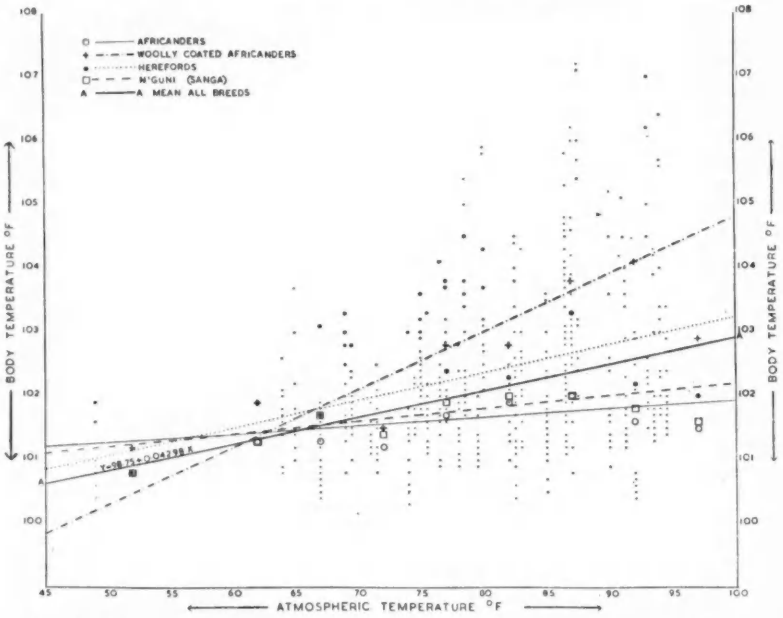
The statistical analysis of the data on the weight loss of cattle of the different breeds and types which calved shows that the Shorthorn cattle lost significantly (P 0·05) more weight than the cross-breds, Africanders, Herefords, and N'gunis.

The Herefords and cross-breds lost less weight than the Africanders and N'guni cattle, probably because these cattle received preferential treatment in grazing. That the Herefords at the Mara and Messina research stations have become more adaptable during recent years as a result of strict selection for smooth-coatedness cannot be denied. Figures

to be given later in this paper also show that the mortality-rate has decreased as a result of breeding for increased adaptability.

There was no statistically significant difference in weight-loss between the groups of N'guni and Africander cows.

Statistical analysis of the data discloses that there existed very large differences in the weight-loss of different animals within the same breed. This variation for cows with calves in respect of Africanders, cross-




Graph 1 illustrates the body-temperature reactions of different types and breeds of cattle. Note the drastic reaction of woolly-coated Africander and even smooth-coated Hereford cattle to high atmospheric temperatures. The Africander and N'guni cattle do not suffer when exposed to the direct impingement of the sun. From the scatter-graph it is obvious how drastically some individual animals react on hot days.

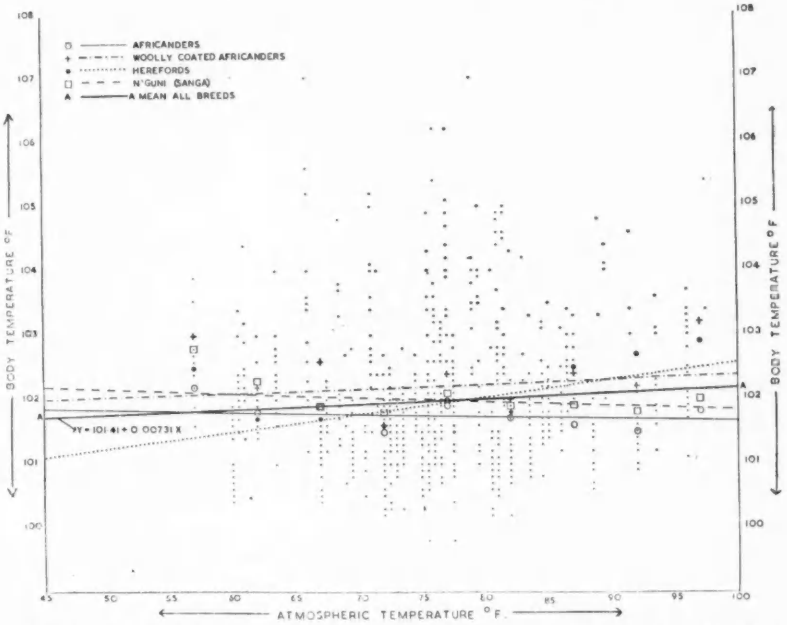
breds, and British beef-breeds ranges from 55 lb. (5·8%) to 420 lb. (35%), 10 lb. (1%) to 345 lb. (31%), and 60 lb. (6·3%) to 425 lb. (38·5%) respectively. It is certain that these variations in weight can form a useful basis in the selection of cattle for increased adaptability. It was, for instance, found at Mara that notwithstanding the fact that certain cows produce more milk and have heavier calves at weaning, they lose less weight during drought periods than other cows of the same breed run in the same camp. In future this aspect of selection will receive much more attention at Mara and Messina.

Lowered calving percentage is the first physiological response to adverse climatological and nutritional conditions. From the calving per-

centages in Table 5 it is clear how adversely the Messina environment affects the improved breeds (British) of livestock, as well as an indigenous breed (the N'guni) of livestock adapted to the *humid* sub-tropics.

Table 6 gives the weight fluctuations of mature cows of different breeds and types at Mara.

Statistical analyses of the data reveal that the Herefords lost significantly (P 0·05) more weight during the 1952 drought year than did the




Graph 2 gives the body-temperature reactions of the same animals (see Graph 1) in the shade. By comparing these graphs it is obvious how important the provision of shade is to livestock production in the tropics and sub-tropics. The value of shady shelters cannot be overemphasized.

cross-breds or Africanders. There was no significant difference between the weight-losses of Africander and cross-bred cattle. It is, therefore, obvious that the indigenous cattle and the cross-breds overcome the hazards of a severe drought better than do cattle from highly improved exotic beef-breeds, notwithstanding that these animals have for three generations been selected for greater adaptability to tropical and sub-tropical environments. Although selection and breeding of Hereford cattle for increased adaptability to tropical and sub-tropical climates have increased their adaptability to the Mara environment and lowered the mortality-rate appreciably, they are still not as robust and resistant as the indigenous stock.

There is no doubt that lack of adaptability in livestock results in a

TABLE 5. *Calving Percentages and Weight Fluctuations of Different Types and Breeds of Cattle at the Messina Station*

| *Breed or type* | *No. of cows in group* | *No. of calves born* | | *Calving percentage 1950–1* | *Calving percentage 1951–2* | *Maximum average weight 1951 (lb.)* | *Minimum average weight 1951 (lb.)* | *Average weight loss % 1951* | *Maximum average weight 1952 (lb.)* | *Minimum average weight 1952 (lb.)* | *Average weight loss % 1952* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *1951* | *1952* | | | | | | | | |
| Africander . . | 28 | (2) 19 | (1) 25 | 68 | 89 | 1,031 | 842 | 18 | 1,135 | 898 | 21 |
| Af. × Ex. cross-bred . | 52 | (4) 36 | (4) 50 | 69 | 96 | 983 | 853 | 13 | 1,117 | 962 | 14 |
| Exotic . . . | 58 | (1)[1] 9 | (8) 36 | 15·5 | 68 | 865 | 686 | 21 | 997 | 812 | 19 |
| N'guni . . . | 29 | (1) 13 | (0) 25 | 48 | 86 | 763 | 614 | 20 | 862 | 666 | 23 |
| Total average . . | 161 | 77 | 138 | 48 | 87 | 907 | 751 | 17 | 1,030 | 849 | 18 |

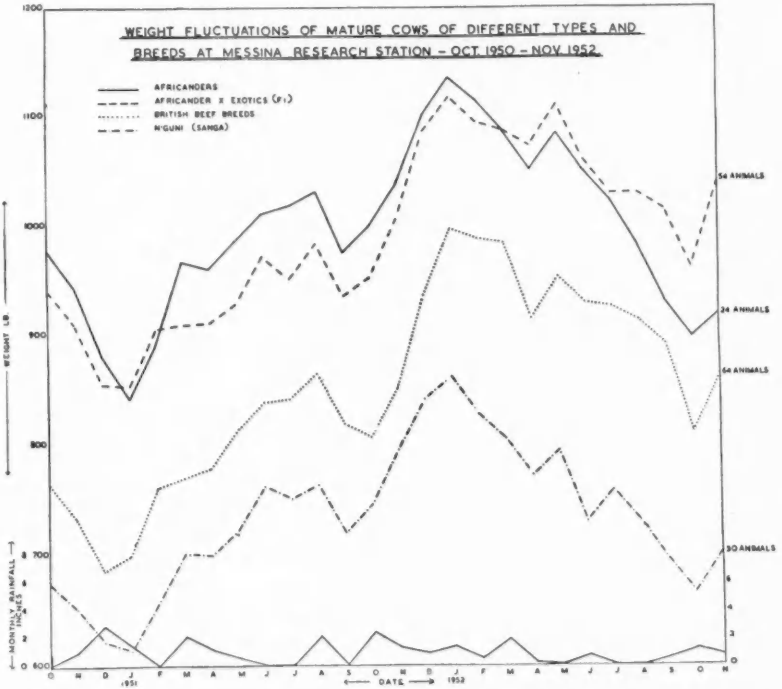
[1] Three out of the 9 calves born in 1951 were stillborn.
The cows tested negative to C.A. Figures in brackets number dead before age of 1 year.

TABLE 6. *Fluctuations in Weight of Mature Cows at Mara*

| *Breed or type* | *No. of cattle in each group* | *Calving percentage 1950–1* | *Mortality percentage 1950–1* | *Calving percentage 1951–2* | *Mortality percentage 1951–2* | *Maximum average weight 1951 (lb.)* | *Minimum average weight 1951 (lb.)* | *Weight loss % 1951* | *Maximum average weight 1952 (lb.)* | *Minimum average weight 1952 (lb.)* | *Average weight loss % 1952* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Africander . | 236 | 86·9 | 7·5 | 80·7 | 4·6 | 1,211 | 1,091 | 9·9 | 1,230 | 1,026 | 16·6 |
| Af. × Ex. cross-bred . . | 180 | 86·8 | 6·1 | 80·2 | 4·2 | 1,206 | 1,067 | 11·5 | 1,289 | 1,056 | 18·1 |
| Hereford . . | 73 | 98·1 | 19·8 | 88·8 | 14·7 | 1,129 | 971 | 14·0 | 1,182 | 930 | 21·3 |
| Total average . | 489 | 89·0 | 7·8 | 82·0 | 5·7 | 1,186 | 1,061 | 10·5 | 1,241 | 1,022 | 17·6 |

higher mortality-rate. In 1949 mortality figures of cattle at Mara were published, giving the average mortality-rate of calves up to 1 year of age born at Mara from 1936–45. (*J. Agric. Science*, vol. 39, part 2.)

The data in Table 8 show that the mortality-rates of the cross-breds and Herefords have been lowered by selection and breeding for in-




Graph 3 shows the weight-fluctuations of mature cows of different types and breeds at the Messina research station. This station lies in a summer-rainfall area. From October until April is the rainy season. A dry spell is experienced every year from May until September. Cattle usually reach their maximum weight in May and minimum weight in October. If summer rains are delayed cattle lose much weight during October and November. The average annual weight-loss varies from 15 to 30 per cent., depending upon the season.

creased adaptability. It is especially marked in the Herefords, where the average rate for calves has been reduced from 34·78 to 27·4 per cent. It has not been possible during the past 10 years to reduce the mortality-rate among Africander calves as a result of breeding for increased adaptability. Rather, the selection and breeding policy have been directed towards increased fertility, milk production, and capacity for growth.

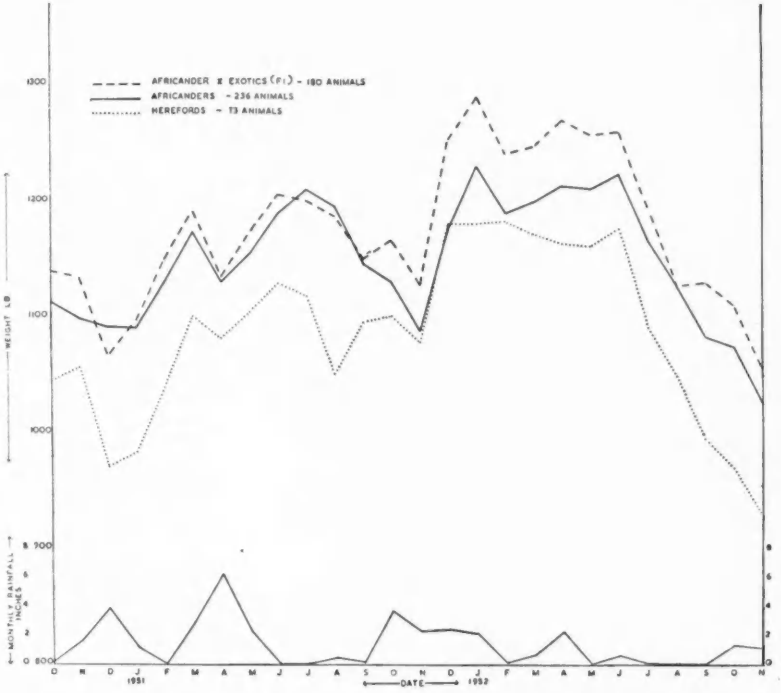
During the past season Mara Research Station experienced one of the severest droughts in its history; only 11·4 in. of rain in 50 precipitations

TABLE 7. *Summary of the Mortality-rate of Calves of Different Types and Breeds at Mara up to one year of age born there during the period 1936–52*

| *Year* | *Africander calves born* | *Africander calves dead* | *Cross-bred calves born* | *Cross-bred calves dead* | *Hereford calves born* | *Hereford calves dead* | *Total born* | *Total dead* | % |
|---|---|---|---|---|---|---|---|---|---|
| 1936–45 . | 308 | 24 | 1,101 | 149 | 69 | 24 | 1,478 | 197 | 13·33 |
| 1946 . | 52 | 5 | 240 | 50 | 31 | 12 | 323 | 67 | 20·74 |
| 1947 . | 67 | 10 | 350 | 31 | 45 | 11 | 462 | 52 | 11·26 |
| 1948 . | 85 | 4 | 324 | 25 | 81 | 16 | 490 | 45 | 9·18 |
| 1949 . | 98 | 12 | 299 | 30 | 74 | 22 | 471 | 64 | 13·59 |
| 1950 . | 135 | 8 | 315 | 57 | 50 | 16 | 500 | 81 | 16·2 |
| 1946–50 . | 437 | 39 | 1,528 | 193 | 281 | 77 | 2,246 | 309 | 13·7 |
| 1951 . | 159 | 12 | 342 | 21 | 51 | 10 | 552 | 43 | 7·79 |
| 1952 . | 151 | 7 | 289 | 12 | 68 | 10 | 508 | 29 | 5·71 |
| 1951–2 . | 310 | 19 | 631 | 33 | 119 | 20 | 1,060 | 72 | 6·79 |
| 1936–52 . | 1,055 | 82 | 3,260 | 375 | 469 | 121 | 4,784 | 578 | 12·08 |
| Average percentage | .. | 7·77 | .. | 11·50 | .. | 25·80 | .. | .. | 12·08 |

were recorded from October 1951 to October 1952, compared with the average of 16·6 in. Only once, in April 1952, was a substantial precipitation of 1·30 in. recorded (Graph 4).

From all the data presented so far it is obvious that adjustment to semi-arid sub-tropical environment involves in livestock not only a high




Graph 4 illustrates the weight-fluctuations of mature cows of different types and breeds at Mara research station. This station is in a summer rainfall (October–April) area. The winter period (May–September) is dry. During normal years, cattle reach their maximum weight during May and minimum weight during October.

heat-tolerance coefficient, but also efficient utilization of the available feed (Graphs 5 and 6).

At Messina station where the climatic and nutritional conditions are really trying, large breeds and types of livestock such as the Africander and the cross-bred Africander cattle do exceedingly well, and cows averaging 1,100 lb. and more can be economically kept in that environment provided adaptable types and breeds are maintained (Plate 3).

From the above data it is also clear that in an effort to produce more beef per unit area in our sub-tropical, semi-arid ranching areas, breeders should consider what are the limiting factors in their environment as well as in their cattle. Cattle should be selected for adaptability to high

TABLE 8. *Average Percentage Mortality-rate of Calves up to 1 Year of Age for the Different Types of Cattle*

| *Period* | *Breed* | *Total born* | *Total dead* | *Percentage dead* |
|---|---|---|---|---|
| 1936–45 . | Africander | 308 | 24 | 7·79 |
| (10 years) | Cross-bred | 1,101 | 149 | 13·53 |
| | Hereford | 69 | 24 | 34·78 |
| 1936–45 . | All breeds | 1,478 | 197 | 13·33 |
| 1946–50 . | Africander | 437 | 39 | 8·92 |
| (5 years) | Cross-bred | 1,528 | 193 | 12·63 |
| | Hereford | 281 | 77 | 27·40 |
| 1946–50 . | All breeds | 2,246 | 309 | 13·76 |
| 1951–2[1] . | Africander | 310 | 19 | 6·13 |
| (2 years) | Cross-bred | 631 | 33 | 5·23 |
| | Hereford | 119 | 20 | 16·81 |
| 1951–2 . | All breeds | 1,060 | 62 | 5·85 |
| Total . | Africander | 1,055 | 82 | 7·77 |
| 1936–52 . | Cross-bred | 3,260 | 375 | 11·50 |
| (17 years) | Hereford | 469 | 121 | 25·80 |
| Grand total | All breeds | 4,784 | 578 | 12·08 |

[1] The figures for 1951–2 are not complete as the calves born during the calving season June–July 1952 are not 1 year old. Only during the years 1951 and 1952 were the calves inoculated against Heartwater before the age of 2 weeks.

atmospheric temperatures and for efficiency of feed-utilization. It is remarkable how well the cross-bred cattle do under the Mara conditions.

It is also remarkable that the N'guni cattle, a small breed, generally considered very hardy, should lose weight so rapidly during the drought conditions at Messina, and it would appear that the N'guni is not a breed to be recommended for the semi-arid sub-tropical regions. During the investigations of the Indigenous Livestock Committee it was, however, observed that the N'guni cattle do better in the humid sub-tropics than Africander and other breeds of cattle.

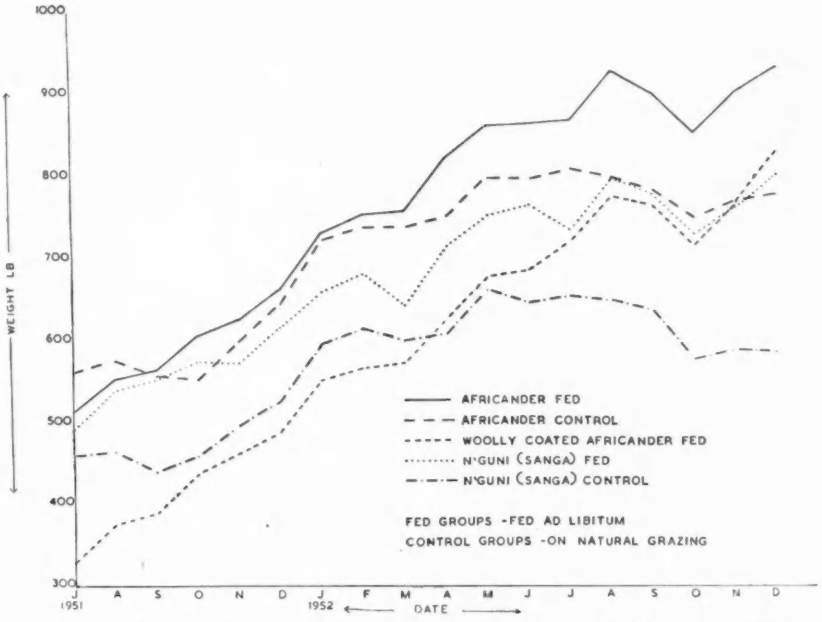
As revealed by these data and from observations made on several visits to various parts of southern Africa and the U.S.A. and one visit to Australia, it is obvious that the breeds and types of cattle found in, and adapted to, semi-arid sub-tropical regions are not small-framed cattle, these being found instead in humid sub-tropical regions and also in areas where the soils are acid. From weight-data and measurements taken on N'guni cattle (Sanga) at Mpisi research station in Swaziland, it was found that the N'guni cattle attain on an average a weight and size which are approximately 65 per cent. of those of Africander cattle (Table 9).[1]

If small size is an advantage in adaptability to semi-arid sub-tropical

[1] Africander cattle measured at Mara Research Station and N'guni cattle measured at Mpisi Research Station, Swaziland.

areas, one would expect cattle of the N'guni (Sanga) breed to do as well as, or better than, Africander cattle under Messina conditions. This is not the case, however, for Africander and cross-bred Africander × exotic beef-breed cattle thrive much better at Messina even during severe droughts (see Graph 5 and Table 9).

In a preliminary trial small groups of cattle of different types and




Graph 5 illustrates the comparative growth of fed groups of Africander, Woolly Africander, and N'guni cattle, and control groups of Africander and N'guni cattle.

breeds were fed as much hay as they could consume in addition to a grain-mixture not exceeding 8 lb. per day. Comparative groups were run on veld without supplementary feed. Comparisons were made of the feed-intake of the different types and breeds of cattle as well as their efficiency of feed-utilization, and also between the supplementary-fed and control groups. Africander cattle proved to be much better adapted to a semi-arid sub-tropical environment and more efficient utilizers of feed than the N'gunis, as is clearly revealed in Table 10, which indicates the average amount of feed consumed by each type of animal.

Table 11 indicates the weight relationship between fed and control groups of cattle of the different breeds.

The outstanding feature of this preliminary trial is that the N'guni cattle, although a small breed with a lower maintenance requirement than the Africander, have greater difficulty in maintaining their

TABLE 9. *Weights and Measurements of N'guni and Africander Cattle in Swaziland*

| Cattle | Age-group | Average live-weight (lb.) | Length of body (cm.) | Height at hips (cm.) | Height at withers (cm.) | Chest circum-ference (cm.) | Depth of chest (cm.) |
|---|---|---|---|---|---|---|---|
| Africander Females | 1 year | 482 | 115 | 113 | 108 | 136 | 46 |
| N'guni Females | 1 year | 315 | 98 | 104 | 99 | 120 | 40 |
| Africander Females | 2 years | 779 | 140 | 130 | 126 | 164 | 61 |
| N'guni Females | 2 years | 457 | 118 | 118 | 113 | 138 | 53 |
| Africander Females | Mature | 1,190 | 154 | 134 | 132 | 187 | 68 |
| N'guni Females | Mature | 723 | 135 | 122 | 122 | 157 | 60 |
| Afr. bulls | Mature | 2,000 | 175 | 142 | 146 | 224 | 76 |
| N'guni bulls | Mature | 1,385 | 152 | 132 | 133 | 177 | 67 |

weight than Africander cattle under semi-arid sub-tropical conditions. These results are confirmed, moreover, in the large groups of mature cattle, where the data prove that the N'guni cattle lose relatively more weight than the Africanders or cross-breds during periods of feed scarcity.

On December 15, 1952, when the different groups of cattle were last measured and weighed, the control group of N'guni cattle attained only 73·1 per cent. of the weight of the fed group of N'guni cattle, but with the Africanders the controls attained a weight equal to 83·3 per cent. of the fed group (Plates 5, 6, 7). Furthermore, the control group of Africander cattle weighed almost as much as the group of fed N'guni cattle (as shown in Graph 5).

The woolly-coated Africander cattle, which are the progeny of a mutant pure-bred Africander bull, had very low heat-tolerance coefficients during the first year after birth; thereafter they improved. As shown in previous publications, cattle have a much lower heat-tolerance coefficient at a very young age and they grow slowly; hence the low weaning-weight of woolly-coated Africander cattle. It is noteworthy that the smooth-coated calves by the woolly-coated Africander bull grow as fast as the other smooth-coated Africander calves. There can be no doubt that smoothness of coat is a valuable asset to cattle in the tropics and sub-tropics.

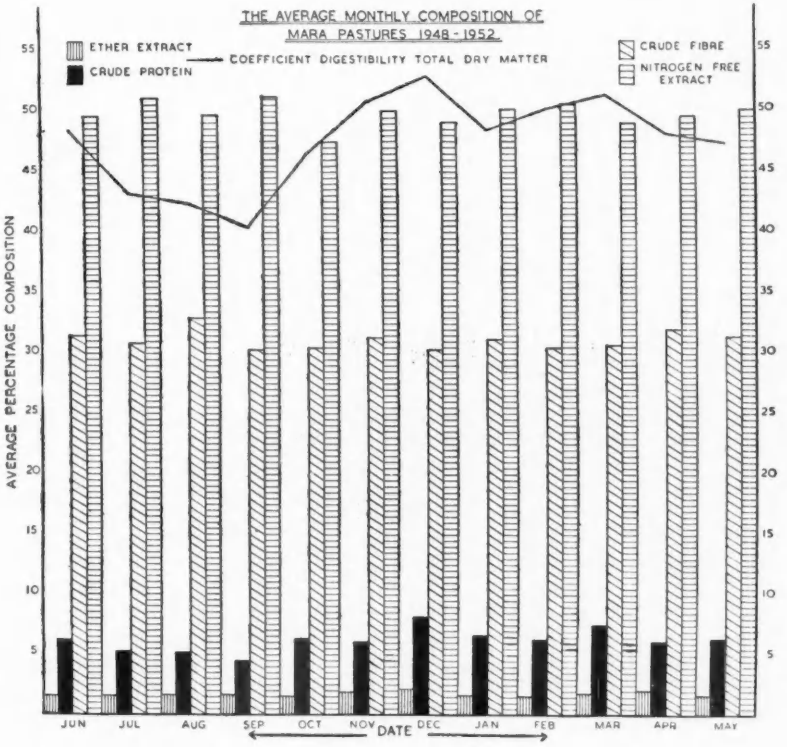
In previous publications the senior author has shown that selection for smooth-coatedness is necessary to improve the adaptability of the British beef-breeds to the semi-arid sub-tropical conditions. The comparison between the pure bred woolly-coated and smooth-coated Africander cattle proves this contention beyond doubt.

## *Conclusions*

From the climatological research work carried out at Mara and Messina, and from precise observations made on the behaviour and

reactions of types of cattle encountered in various climatic regions, certain suggestions can be made concerning the improvement of livestock production. The following principles should govern the selection of cattle adapted to semi-arid sub-tropical environments:

1. Select cattle with thick movable hides and a very smooth coat.

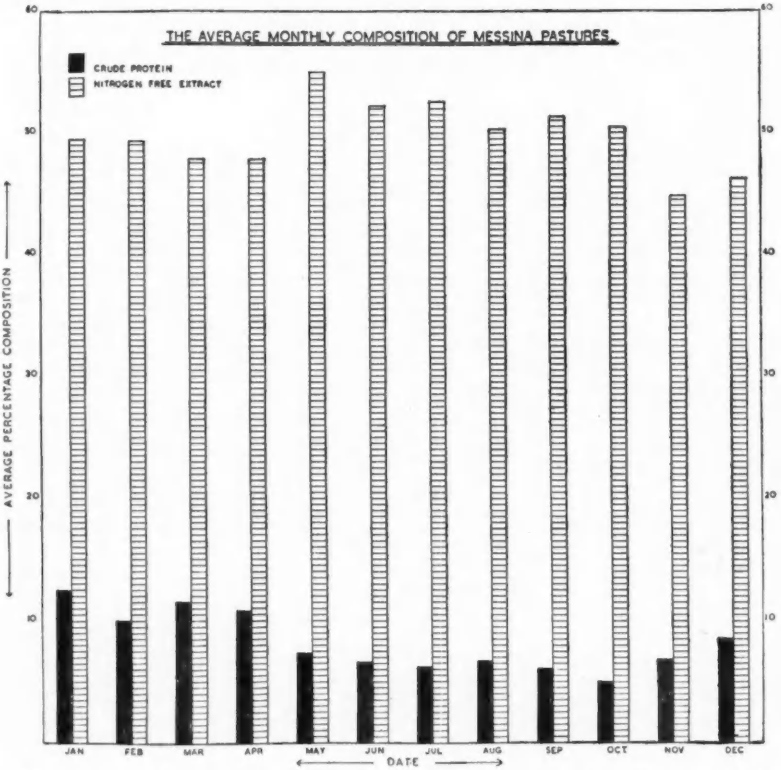



Graph 6 illustrates the 4-year average monthly composition and digestibility of Mara pastures. The limiting factor in livestock production in the semi-arid sub-tropics is not pasture composition but total digestible nutrients (T.D.N.) per unit area during periods of drought.

2. Select the early hair-shedders, i.e. calves that shed their calf coats early during the first spring after birth. Such cattle are 'good doers' in a semi-arid sub-tropical environment.

3. Select for future breeding cows that are regular calvers and produce calves heavy at weaning age. Cows that are selected on the performance of their calves must be adaptable, because an unadapted cow cannot calve regularly and produce an abundance of milk to enable her to wean a heavy calf.

4. Cows that do not lose much weight during a season of drought and are still able to raise calves that thrive, are good cows. It is an aspect of selection for adaptability which is going to receive much attention in the future selection and breeding policy at Mara.




Graph 7 depicts the average monthly composition over a 3-year period of Messina pastures in respect of protein and nitrogen-free extract. Grazing cattle were followed, and grab samples were taken of edible bush, shrub, and pastures as consumed. The protein-content of Messina pastures is high because so much of the available grazing is composed of the leaves and pods of bush and shrubs.

5. Longevity is another physiological trait which is taken into consideration in breeding for increased adaptability. More than 10 per cent. of the Africander cows at Mara are over 16 years of age.
6. Bulls are selected on the basis of the fertility and milk production of their dams, and the progeny of bulls should be tested for growth capacity, efficiency of food utilization, fertility, and milk production.

In an effort to place breeds and types of cattle in environments in

TABLE 10. *Comparison of Feed-utilization by Africander and N'guni Cattle*

| *Breed* | *Average commencement weight 15/7/51 (lb.)* | *Average weight 15/11/52 (lb.)* | *Total gain in weight (lb.)* | *Average total hay consumed per animal (lb.) (487 days)* | *Average total grain consumed per animal (lb.) (487 days)* | *Average total T.D.N. consumed per animal (lb.) (487 days)* | * *Average daily T.D.N. needed for maintenance (lb.)* | † *lb. T.D.N. above maint. required for 1 lb. live-weight gain* |
|---|---|---|---|---|---|---|---|---|
| (Smooth) Africander | 514 | 925 | 411 | 5,259 | 1,680 | 4,320 | 6·5 | 3·0 |
| (Woolly) Africander | 328 | 768 | 440 | 4,451 | 1,680 | 3,847 | 5·0 | 3·25 |
| (Very smooth) N'guni | 492 | 767 | 275 | 5,069 | 1,674 | 4,204 | 5·7 | 5·20 |

* Calculated from recommended nutrient allowances for beef cattle, N.R.C., Washington D.C.
† Calculated as follows: $\frac{\text{Total feed-consumption lb. T.D.N.} - \text{Total maintenance requirements lb. T.D.N.}}{\text{Total weight gain in pounds}}$

TABLE 11. *Weight Relations between Fed and Control Groups of Africander and N'guni Cattle*

| *Breed* | *Treatment* | *Average weight 15/12/52 (lb.)* | *Weight-difference between fed and control groups in each breed (lb.)* | *Average weight of respective control groups as % of aver. wt. of fed group* | *Average weight of N'guni cattle as % of the respective Africander* |
|---|---|---|---|---|---|
| Africander (4) | Fed | 938 | .. | 83·3 | 86 |
| Africander (4) | Control | 782 | 156 | .. | .. |
| N'guni (4) | Fed | 807 | .. | .. | 75 |
| N'guni (4) | Control | 588 | 219 | 72·8 | .. |

which they should be adapted, the following broad suggestions are made:

(*a*) In semi-arid, sub-tropical savannah environments, where very often alkaline soils predominate, breeds of large cattle such as Africanders and Africander cross-breds that are smooth-coated, have thick hides and well developed dewlap and umbilical fold, are recommended. Vast areas of the Transvaal Bushveld, Bechuanaland, and of Central and Northern Australia have such areas.

(*b*) In high altitude, semi-arid regions, such as are found in parts of south-west Africa, it is suggested that Sussex, Hereford, and Angus cattle be maintained in the areas with a high nutritional level. In areas where the nutritional conditions are poorer and temperatures are higher, Africander and Africander cross-bred types are recommended.

(*c*) In tropical and sub-tropical humid climates, where acid soils and sour veld predominate, small breeds of cattle of the *Bos indicus* type (N'guni and Sanga) are recommended. These areas include the coastal areas of Zululand, humid areas of Swaziland, Mocambique, &c.

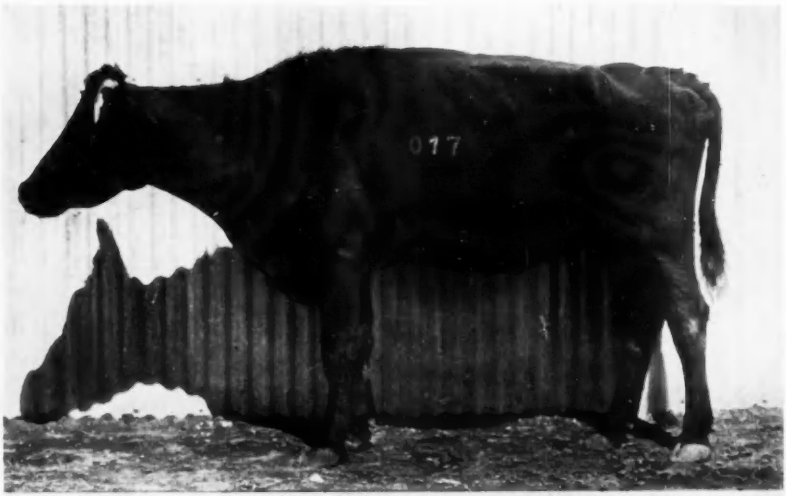
(*d*) In sub-tropical climates of high altitude and high rainfall such as are encountered in the high-altitude ranching areas of Southern Rhodesia, Hereford and Aberdeen Angus beef cattle are recommended where intensive crop-growing is practised. In the extensive areas the *Black Bos indicus* (Mashona) type of indigenous cattle should be crossed with Aberdeen Angus cattle to improve the conformation as well as the efficiency of feed-utilization of the Mashona type of cattle. In these sub-tropical areas of high altitude and high rainfall, the natural nutritional conditions are poor, and small-framed black cattle that are efficient feed-utilizers should do best.

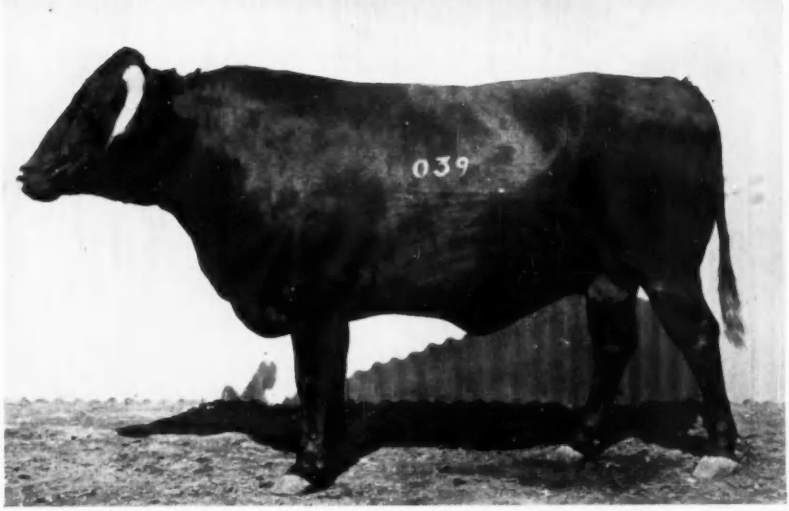
(*e*) In intensive beef-cattle producing areas, as well as in semi-intensive ranching areas where the soils are alkaline, the pastures sweet, and nutritional conditions are good, the Shorthorn beef-breed of cattle does best.

From all the climatological research work done at Mara and Messina, as well as from observations made at Koopmansfontein Research Station, C.P., Neudam near Windhoek, SW. Africa, and from those made on farms in various parts of the world, there can be no doubt that the Shorthorn is the least adaptable of the British beef-breeds of cattle to semi-arid, sub-tropical extensive ranching conditions.

In adopting cattle-breeding policies for Colonial development a few salient points should be taken into consideration, namely that all breeds of livestock have moderate powers of adaptability, but that beyond certain limits the animal's constitution breaks down and it succumbs or does not reproduce.

Smooth-coated crossbred cattle adapted to subtropical semi-arid regions. These cattle were maintained at Mara under veld conditions and were photographed at the end of the drought in 1952.




Differences in body conformation between adapted and non-adapted cattle. These cows were maintained under identical environmental conditions, and were fed a maintenance ration during periods of poor veld conditions.

017—Pure-bred Shorthorn. Born 26/12/39. Photographed 14/12/52. Age 13 years—had 4 calves. Weight 30/11/52—765 lb.

039—$\frac{3}{4}$ Africander × $\frac{1}{4}$ Shorthorn. Born 26/12/39. Photographed 14/12/52. Age 13 years—had 8 calves. Weight 30/11/52—1045 lb.

Cattle unadapted to the sub-tropics develop ewe-necks, slack loins, and small rumps; become deep and flat through the chest and lack stomach capacity (Response physiology).

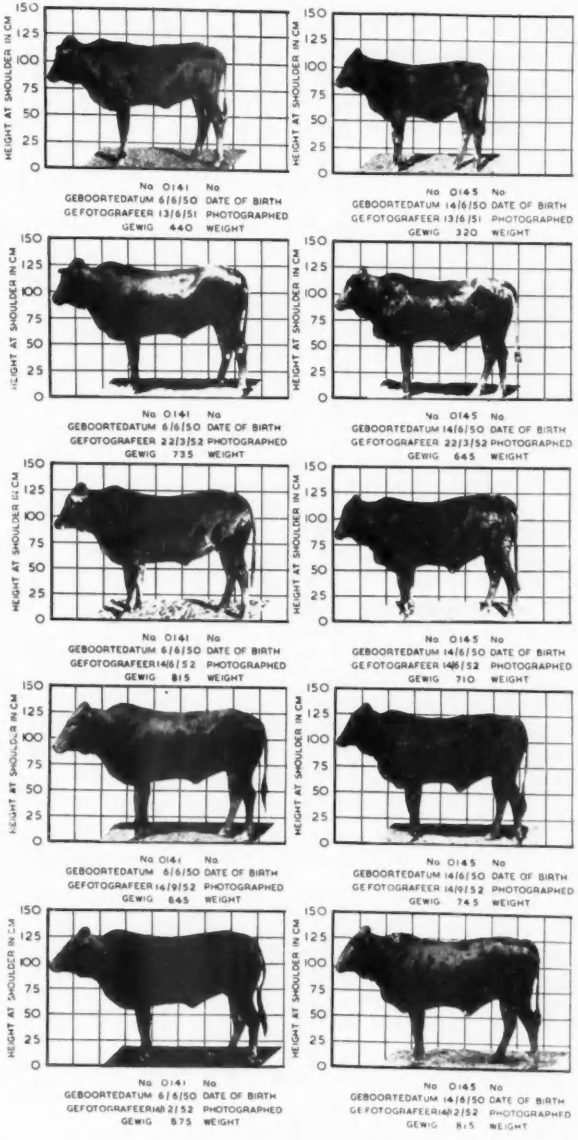



Illustration of the relative growth of fed smooth-coated and woolly-coated Africander cattle. The woolly-coated cattle have a low heat-tolerance coefficient during the first two years, with the result that growth is retarded.

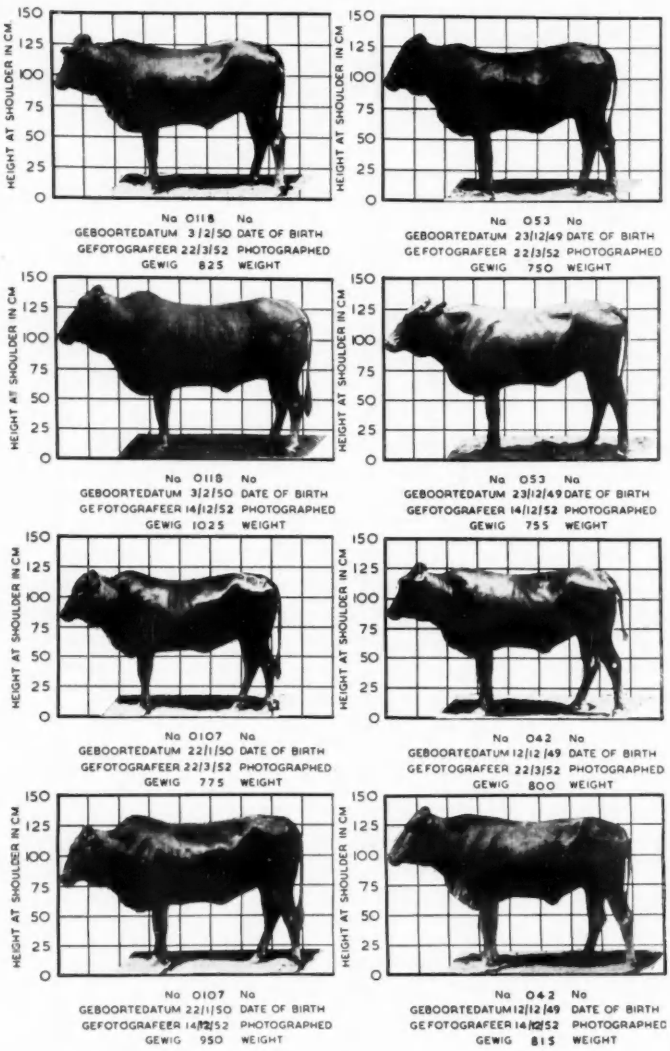



Illustration of the relative growth between fed and control groups of Africander heifers. At the end of March, end of the 1952 summer season, there was only 19 lb. or 2·5 per cent. difference between the fed and control groups. At the end of 1952, that is after a drought, the average differences between the fed and control groups was 132 lb. or 14·6 per cent. Note the difference in development between the two groups. The control group (right) are long legged and short bodied, and they lack loin and rump development.

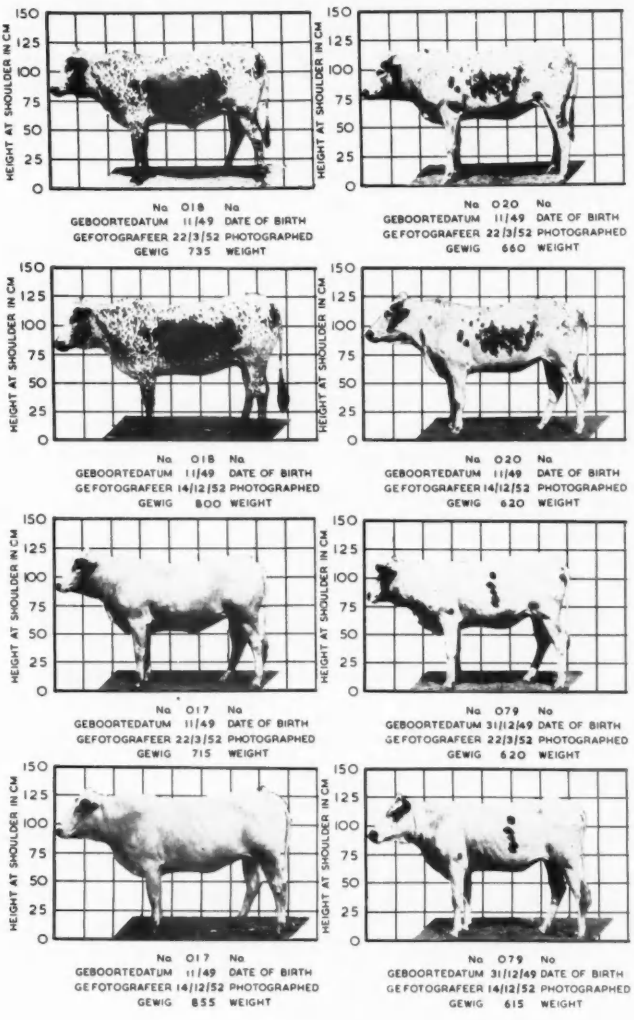



Illustration of the comparative growth of fed (right) and [illegible]

## ERRATUM

*Plate 7: 1st line of description, read* 'fed (left) and control (right)'

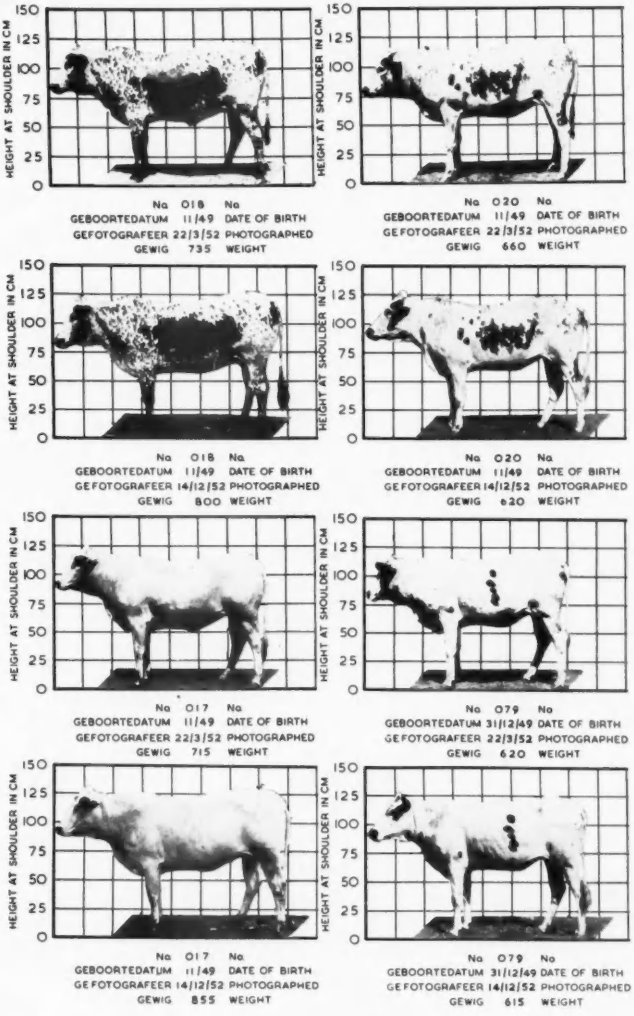



Illustration of the comparative growth of fed (right) and control (left) Nguni cattle. At end-March 1952, the average difference in weight between the fed and control groups was only 44 lb. or 6·8 per cent. At the end of the 1952 drought-year (November 1952) the average difference was 176 lb. or 22·9 per cent. Note that in the control group of Nguni cattle the same developmental changes occur as in the control group of Africander heifers, namely the loin and rump development is retarded and length of leg and height at shoulder increased. The body-conformation is, however, not changed to the extent of that in the Shorthorn cow.

The nature of the environment in which cattle are to be kept, determines the types which should be maintained.

In formulating a breeding policy, full use must be made of the useful dominant characteristics of different breeds of cattle by judicious cross-breeding. The efficiency of feed-utilization and 'beefing' qualities of the improved British beef-breeds of cattle should be combined with the hardiness, heat-tolerance, and foraging ability of the indigenous breeds.

In certain areas pure breeds of livestock have been evolved that are adapted to their environment and are efficient utilizers of feed; in such regions cross-breeding is not recommended.

To make livestock husbandry a success, the environment, the animal, and the continuous adjustment between the two sets of phenomena that constitutes life, should be studied. By careful selection and proper range management it is possible to produce the maximum amount of beef per unit area.

*Summary*

In this paper data are presented on fertility, rate of development, and differential resistance to disease and mortality of different types and breeds of cattle in semi-arid, sub-tropical environments.

Accurate data clearly illustrate how lack of adaptability in a breed of livestock to a particular environment results in slow growth, low fertility, and high mortality, causing financial failure of ranching enterprises which did not take into account the important relationship between environment and livestock production.

Data are presented on the weight losses of different types and breeds of cattle during a severe drought; indigenous cattle and cross-breds overcome this hazard better than do cattle from highly improved exotic beef-breeds.

From data presented it is evident that the mortality rate of cross-bred and Hereford cattle has been lowered by selection and breeding for increased adaptability.

Suggestions are made in connexion with the improvement of livestock production in semi-arid, sub-tropical environments and the principles that should govern the selection of cattle adapted to such regions are enumerated.

Broad suggestions are made with reference to the placing of different types and breeds of cattle in environments to which they should be adapted.

(*Received February 2, 1953*)

# A SURVEY OF THE VALUE OF FERTILIZERS TO THE FOOD-FARMING AREAS OF THE GOLD COAST

## PART 1. AIMS AND METHODS OF THE SURVEY

P. H. NYE[1]

THE Gold Coast has at present no examples of the use of fertilizers on any appreciable scale. On the other hand, field experiments that were conducted at agricultural stations in 1948 and 1949 showed that in many areas phosphatic, and to a less extent nitrogenous, fertilizers might give profitable increases in the yields of the main annual food crops [1]. The present survey aimed at determining the fertilizer requirements of the main crops in twelve heavily farmed areas of size varying from 200 to 2,450 square miles, by means of large numbers of small-scale trials on native farms. The intention was to find how far previous work at experimental stations applied to the actual conditions of food production in the country, and to obtain an accurate estimate of the value of fertilizers, so that plans could be made to introduce them to farmers on a large scale. It is necessary to emphasize the danger of introducing new techniques solely on the basis of trials at experimental stations where the previous treatment of the land and the nature of the soil can at the best represent a very small sample of the variety of conditions likely to be found in a farming area, and at the worst be quite atypical.

Previous work at experimental stations showed that the responses to be expected from fertilizers were greatly influenced by the natural vegetation and cropping history of the land. Available nitrogen was more deficient in savannah areas than forest, and was particularly deficient on land freshly cleared from a long grass-fallow. Available phosphorus was more deficient in areas with a long-cropping and short-fallow period, and responses were not so great on land that had received kraal manure. It was therefore very important in these experiments to cover the whole range of cropping conditions in the areas selected with a large number of experimental sites. The history of each site, so far as it was known, was recorded, so that the difference in responses between one class of sites and another has been determined, as well as the average over an area.

### *The Area Surveyed*

It was impossible, with the existing staff of the Agricultural Department and comparatively poor communications, to survey the whole country; and indeed this was not really necessary. In the first place extension work for many years will be largely confined to the more densely farmed areas. Secondly, these are the most exhausted areas, and they most need fertilizers. Where there is abundant land, fallows will be long, and the previous experiments, confirmed by the present series, showed

[1] Lecturer in Soil Science, University College, Ibadan, formerly Agricultural Chemist, Gold Coast.

[Empire Journ. of Exper. Agric., Vol. 21, No. 83, 1953.]

that in these conditions phosphorus will give poor returns. It is true that in the Voltaian tall-grass savannah there are vast tracts only occasionally farmed, where available nitrogen is deficient, but the areas selected include some sites of this nature, and it is almost certainly safe to regard the nitrogen responses of these sites as typical of the whole sparsely populated Voltaian savannah areas.

The situations and boundaries of the areas surveyed are shown in Fig. 1. The information given in Table 1 summarizes their essential differences and similarities.

TABLE 1. *Summary of Conditions in the Areas Surveyed*

| | *Area* | *Parent material of soil* | *Natural vegetation* | *Size (approx.) (sq. miles)* | *Population (thousands)** | *Trial crops* |
|---|---|---|---|---|---|---|
| Northern Territories | Bawku | Northern Granitic | Savannah | 900 | 108 | Early millet, late millet, guinea corn, and groundnuts |
| | Zuarungu (ex. Nangodi) | | | 500 | 104 | |
| | Navrongo | | | 520 | 48 | |
| | Lawra | | | 2,450 | 142 | |
| | Nangodi | Greenstone | Savannah | 125 | 26 | do. |
| Ashanti | Tamale | Voltaian Sandstone | Savannah | 1,000 | 36 | Yams, maize, guinea corn, and rice |
| | Yendi | | | 1,870 | 34 | |
| | Ejura | | | 290 | 11 | |
| | Wenchi | | | 1,600 | 18 | |
| Colony | Krobo | Sandstone | Forest | 430 | 43 | Maize |
| | Nsawam | Granitic | | 200 | 41 | do. |
| | Keta | Sandy Clay | | 360 | 59 | do. |
| | | | | 10,245 | 670 | |

* The population figures, which are based on the Gold Coast Census of Population, 1948, are very approximate, since the trial areas are usually bounded by major soil changes or convenient graticules, and by no means coincide with the administrative divisions on which the census is based.

The total area of the Gold Coast (including Togoland) is 91,843 sq. miles, and the population is 4,118,000; so that approximately one-ninth of the total area has been surveyed, and this includes about one-sixth of the total population. In the Northern Territories, where there are no large towns and nearly the whole adult population is engaged in food-farming, one-ninth of the total area was surveyed, but this included one-half of the population.

A short description of the climate, natural vegetation, soils, and farming systems of the Gold Coast has been given previously [2] and at this point it is only necessary to describe briefly the places selected areas occupy within the whole country. The conditions particular to each area will be considered in greater detail when the results for the area are described (in Pts. 2 and 3, to follow).

The Bawku, Zuarungu, Navrongo, and Lawra areas, which are administrative divisions, together cover the whole of the densely farmed soils developed over granite, granodiorite and granitic gneiss, and schist

in the Northern Territories. The unsurveyed granitic soils to the east and south of the Lawra area are sparsely populated. To the east of the Zuarungu area, in the neighbourhood of Nangodi, a belt of greenstone gives rise to much-farmed friable brown, orange, and red loams and clays, in contrast to the sands and sandy loams developed over the granitic

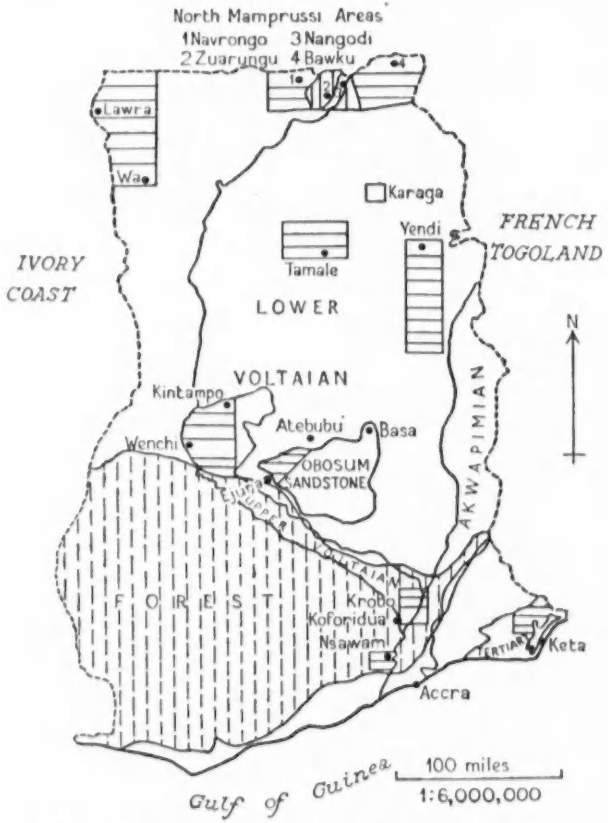



FIG. 1. Sketch map of areas surveyed in the Gold Coast.

rocks. The results from these soils have been separated from those of the main Zuarungu area.

The Tamale, Yendi, Ejura, and Wenchi areas include the more densely populated soils in the savannah overlying the Voltaian sedimentary rocks. These are not so heavily populated as the granite soils of the far north and the ratio cropping: resting ranges from 1 : 1 or less near the towns, to 1 : 10 or more. Outside these areas the Voltaian soils are very sparsely populated. The farmed areas overlie the sandstones, the soils over the other rocks, mainly shales, being little used.

In the high forest farmers are mainly interested in cocoa. There are innumerable scattered subsistence farms, but the only important areas producing staple food crops are immediately around the big towns. These areas were considered too small and scattered to justify experiments at this stage.

On the northern fringe of the forest in Krobo, and on the southern fringe around Nsawam, it is too dry for successful cocoa farming and both areas have become important maize-growing centres. The Krobo area cannot be considered very heavily farmed as the ratio of cropping to resting rarely exceeds 1:3; but it usually exceeds 1:1 in the Nsawam area, which lies just north of Accra and is being exploited with rapidly increasing intensity. Grouped with these two areas, but separated from the forest by the almost deserted Accra plains, is a heavily populated area north of Keta. Its natural vegetation is forest, but as the ratio cropping : resting is about 1:1 there is usually only scrub to be seen.

### *Methods of the Survey*

The aims of the survey for each area were:

(*a*) To find out the average response to the fertilizers of each important crop for the whole area.

(*b*) To ascertain whether the responses could be grouped in significant agricultural classes, e.g. responses on manured and unmanured land. To this end the cropping and manuring history and situation of each site were recorded, and a composite sample of the top soil taken. In every area the cropping histories, and in the north the manuring practices, show considerable variations, whose influences are referred to in the account of the results.

In the absence of a soil survey of each area, it was not possible to group the fertilizer responses according to the different soils that might be distinguished. This is not considered too serious a handicap since, from the point of view of annual crops, whose roots are mainly in the humic top soil, between 6 and 12 in. deep, the dry-farmed soils within each area are morphologically fairly uniform. The land is usually undulating, and there is in each area a well-defined topographic sequence of soils developed over the relatively uniform parent rocks. Farming is mainly concentrated on the slopes above the seasonal flood-level. All the top soils are sandy, except in the Nangodi area, and freely draining. For these reasons it is considered that responses to fertilizers in any area are likely to be far more influenced by past usage of the land than by the many subdivisions that could be made in the soils used. A brief description of the soils in each area is given in the appropriate section.

The general plan for the survey was to select at random thirty sites on native farms for each crop-mixture under trial in each area. On every site a standard trial was laid down. The trial was a single replication of a $3 \times 3$ (9 plot) design involving the following treatments in all combinations.

Sulphate of ammonia 0, 60, 120 lb. per acre.
Superphosphate (18·5% water-sol. $P_2O_5$) 0, 60, 120 lb. per acre.

As earlier experiments had shown that there was no object in the

application of nitrogen to groundnuts, on each site with this crop there were three plots only, treated with 0, 60, 120 lb. per acre superphosphate.

The plot-size was $\frac{1}{40}$ acre for all crops. The total trial area of $\frac{9}{40}$ of an acre was small enough to fit within nearly all patches of crops.

The fertilizers were placed with a tea-spoon about 2 in. from the base of each plant. Superphosphate was applied as soon as possible after the plants had germinated, and sulphate of ammonia about 30 days after germination, owing to the risk of depressing the growth of the seedlings in a dry spell, an effect which had been noted in trials at experimental stations. On yams, the fertilizer was placed in a ring near the top of each mound at the beginning of the rains. When crops such as early millet and guinea corn were mixed, the fertilizer was divided equally between the two crops.

The selection of the sites, marking out of plots, spreading of fertilizers, and harvesting were done by the staff of the Agricultural Department. The growing of the crop was entirely the work of the farmer, who treated the trial site in the same way as the rest of his fields; thus the results may be considered a fair sample of those which would be obtained under native farming.

Stewart [3] has discussed the planning of simple fertilizer experiments in cultivators' fields, and a comparison of the methods adopted in the Gold Coast, where the possibilities are thought to be typical of tropical Africa, with those he considered suitable for India is instructive. In the first place small plots of standard size were found preferable to large portions of whole fields. If an effective control over large numbers of experiments conducted by local staff is to be kept, the most rigid standardization of procedure is necessary. With standard-sized plots, the assistant responsible for a group of trials could always carry by bicycle the same amount of fertilizer, ready weighed into bags, to the experimental site; and he soon became used to placing a standard quantity opposite a standard-sized plot for checking before spreading. With large portions of the field different quantities would be needed depending on the size of the fields, which were very variable. Also the amount of fertilizer would be more than a man could readily carry on a bicycle, thus increasing considerably the time taken over one trial at a very busy time.

In the second place Stewart stresses the need for simplicity in experiments on cultivators' fields. However, in the present series very simple designs would not have given the information required; for three levels of N and three levels of P were essential if an idea of the economic response was to be obtained, and previous experiments had indicated that there was a positive interaction between N and P on cereals when the direct effects were high. The results show that provided assistants have to understand only one design, the moderate degree of complication involved in a $3 \times 3$ factorial design is quite feasible. On nearly all farms cultivations are made by hand, and the pegs marking out the plots suffered little interference, far less than they would do in places where cultivations are made with draught animals. The value of the present series as demonstration trials is admittedly reduced, but their primary

purpose was experimental, and it was hoped that recommendations for simple demonstration trials would arise from their results.

On each site a single replication only was used, for, as Stewart points out, it is more important to cover the maximum number of sites than double the number of plots on any one site. Two replications would have enabled the significance of the response at each site to be estimated. Such knowledge is essential when one wishes to establish whether there is a genuine response to a fertilizer on a site, but in the present series it was known that there were, as a rule, significant responses, and it was the magnitude of the average response that was of interest. The estimate of the error of the average response is based solely on the variation in responses between sites. This variation in the responses is itself of interest, because it governs the reliability of recommendations based on the average response. Although the precise statistical significance of this variation can be determined only if the error within each site is known, in the present series the variation is so large that it is clearly significant for any reasonable value of the error within sites. There are also practical difficulties in the way of replication. Farmers could often not allow more than $\frac{1}{4}$ acre of grain to be threshed at a time; all staff were used to the $\frac{1}{40}$-acre plot, and smaller plots would have been very inconvenient; and lastly an inconveniently large amount of fertilizer would have been required.

*Selection of sites.*—The following limitations were placed upon a purely random selection of sites within each area:

1. Each area was stratified into between five and ten districts and the number of sites selected at random in each district was roughly proportional to its population. This should lead to rather more accurate values of average responses than a purely random selection of sites over the whole area. It also simplified the problem of supervision by dividing the area into convenient units. Ideally the number of sites for each crop in each district should be proportional to the acreage grown, a procedure adopted in yield surveys in India [4]. However, in the Gold Coast no survey of the acreage under the different crops in each district has been made, so that the method of stratification was inevitably rough.

2. In the Northern Granitic and Southern Maize Regions there was a reasonable distribution of sites over each district. In the Voltaian Sandstone Region farming is most concentrated around the towns and villages and much of the land is rather inaccessible and less frequently farmed. Many of the sites were on the little-farmed land, but it is likely that this land is under-represented in proportion to the total amount of it under a crop.

3. There were special exclusions placed upon selection of certain sites; e.g. in the far north there is usually a patch of high fertility immediately around the compound so that no sites were allowed within 50 yards of the compound. These limitations are mentioned in the appropriate section.

4. There may be a small element of bias in the fact that the sites selected tended to be on the land of farmers who knew the district officer and were possibly more progressive. This probably makes little

difference except in the far north where it may cause a bias in selection in favour of farmers who used dung.

*Estimates of error.*—For each area the standard error of the mean yield, the $N_2$ and the $P_2$ responses, are estimated from the corresponding variations of the mean, the $N_2$ response, and the $P_2$ response between sites.

Within each main region sites have been divided into groups according to their past treatment, e.g. manured and unmanured sites. The variations in mean yield and responses between sites of one group do not appear to differ significantly from the variations between the sites of the other group, and the two variances have been pooled for the estimate of the error of the mean yield and responses on the sites of each group.

*Organization.*—As this is probably the first comprehensive survey of the value of fertilizers to be made on peasant holdings in Africa, the organization required may be outlined briefly. In each area the trials were conducted by the district assistants who knew the local people well. On the average one assistant was able to manage about fifteen sites with one trial crop, or twenty sites if they were divided between different trial crops and the operations could be staggered. The layout of the plots, the weight of fertilizers to be spread, and the final yields were all checked by a specialist assistant, who could easily manage two small areas or one large one. The periods of greatest strain on the staff are at the time for spreading fertilizers, and especially at harvest time when any delay may mean that the farmer will harvest his crop without waiting. All calculations were made centrally.

In practice there was little difficulty in the Northern Territories, where the main effort lay, in obtaining most of the thirty sites for each crop in every area, and about 70 per cent. of all sites planted were successfully harvested. Casualties were due to the farmers' harvesting without notice, failure to apply fertilizer in time, and failure to check harvest yields. Results from sites in which crops failed are, of course, included in the general means, since such failures would occur in actual practice. In Ashanti and the Colony the required number of sites was nearly always attained except in the Krobo area where the farmers were suspicious and unco-operative. Only about half the yam and rice trials were successfully harvested, losses being due to the farmers' harvesting, and the stealing of yams. The value of the maize trials was reduced by an attack of rust which swept the south, causing very poor yields. In all, 438 sites were successfully harvested.

In the subsequent parts of this series a description of the soils, climate and agriculture, and the experimental results for each of the main groups of areas are presented, the economic value of fertilizers is assessed, and suggestions are made for the best means of using them.

*Acknowledgements.*—This survey was the result of collaboration between the staff of the Division of Chemistry and the field staff of the Agricultural Department in the trial areas. It is a pleasure to record the assistance received from Mr. R. K. Djokoto, who was responsible for much of the co-ordination, and from the Agriculture Officers and their

field staffs; and also to thank Mr. B. M. Church for some valuable criticism of the statistical aspects of this work.

*Summary.*—A series of experiments to determine the average fertilizer responses of the principal crops in the main food-farming areas of the Gold Coast is described. Large numbers of trials of a standard design were laid down in peasant cultivators' fields, and the responses obtained have been correlated with the varying conditions of cropping, manuring, &c., that are found. In this part the geographical setting of the areas is described, and the methods of the survey set out in detail.

## REFERENCES

1. P. H. Nye, Empire J. Expt. Agric., 1951, **19**, 275, 1952, **20**, 47.
2. ——, ibid., 1951, **19**, 217.
3. A. B. Stewart, Colonial No. 214, 1947, H.M. Stationery Office, London.
4. V. G. Panse *et al.*, Current Science, 1945, No. 11, 287.

(*Received December 30, 1952*)

# VIRUS DISEASES OF SWEET POTATO IN PARTS OF AFRICA

F. M. L. SHEFFIELD[1]

ALTHOUGH sweet potatoes are an important native food crop in many tropical countries, reports of suspected virus diseases in them are few. The first [1] came from the United States of America in 1920. This has been followed by several further reports from America but none seems to have come from any other country except Africa. Although it was not at the time recognized as such, probably the first African report of a virus disease in sweet potato came in 1939 from the farm attached to the Kilo Moto Mines in Ituri, Belgian Congo. The degeneration there was at first thought to be due to the method of propagation used and was later ascribed to a fungus, but the measures taken against it were of no avail [2]. In a few years, when a crop which had amounted to 30,000 kg. per annum was reduced to 4,000 kg., sweet potato cultivation was entirely abandoned in this area. During this period, natives near Mulungu-Tshibinda on the western shores of Lake Kivu began to complain of degeneration in their sweet potatoes, and in 1943 the disease was said to be bad in parts of Ruanda-Urundi. It was first reported in East Africa in 1944 when Jameson found it in a collection of native varieties being grown at the Agricultural Experimental Station at Kawanda, near Kampala [3]. Very soon, further reports came of its occurrence in the Belgian Congo, in Ruanda-Urundi, and in Uganda. In Kenya, at this time, it was found only near Kisumu. In 1944 it was feared that the disease might have been a new introduction into the Belgian Congo and might be spreading rapidly eastwards. However, in 1945 Wallace reported its presence in many parts of Tanganyika [4, 5], and the following year it was seen at Nelspruit in Transvaal [6] and in 1949 in Nyasaland. It therefore seems more probable that the disease has been in Africa for a considerable time.

In 1944 observers thought that the disease was probably caused by a virus. Work, based on this hypothesis, was undertaken at several institutions. At Kawanda, Hansford and Jameson made a collection of varieties and studied them for resistance. A moderately resistant strain, *Namujuna*, was selected and is now extensively grown in Buganda. Hendrickx, at Mulungu-Tshibinda, undertook the breeding of plants for resistance and is still continuing this work. Nichols, at Amani, and Nattrass, at the Scott Laboratories, both transmitted a disease by grafting. Neither published his results, and since neither seems to have searched for a visible pathogen, only in the absence of which is graft-transmission regarded as proof of the virus nature of a disease, these results could not be taken as absolute proof of the presence of a virus. Large numbers of white fly were noticed on the crop in many places in 1944, and these were suspected of being vectors of the disease.

[1] East African Agriculture and Forestry Research Organization, Box 21, Kikuyu, Kenya.

[Empire Journ. of Exper. Agric., Vol. 21, No. 83, 1953.]

However, some experiments by Nichols [6], using these insects, gave entirely negative results.

Owing to shortage of staff and more urgent problems, little more was done in the East African Territories until recently.

I have now proved the virus nature of the disease beyond all reasonable doubt. Several hundred plants have been infected by grafting with scions from diseased plants selected in the field. In no case could any signs of any visible pathogen such as bacteria, fungi, eel-worms, &c., be found in the diseased plants. All attempts to transmit a disease mechanically have failed. Search for an insect vector has only just started.

Except at Mulungu-Tshibinda, the general impression of observers who were in Africa at the time seems to be that 1944 was an epidemic year and that the disease has since receded. This may be true; but the observations made on several tours, undertaken as a preliminary to a more fundamental study of the problem, show that the disease remains a potential danger in many parts of Africa.

### *The Disease*

The disease is of the mosaic type but the symptoms shown vary greatly. The most obvious are severe stunting and chlorosis. Internodes may be shortened, so that branching appears excessive. Leaves may be small, are sometimes distorted, are occasionally back-rolled at the extreme margin, and may be toughened and leathery. In varieties with much dissected leaves, they may be reduced to a strap-shape. A distinct vein-clearing may be shown, but this alone cannot be taken as a diagnostic feature since it commonly occurs in the young leaves of some varieties. A brilliant green and yellow mottle may be seen although this is unusual in the field, where mottling is more usually vague and indefinite. Probably only in those varieties which normally have some red pigment in their leaves, a green and bronze mottle may occur on the older leaves. Necrotic patches may occur on the leaves. These are seen also on the older leaves of some varieties when healthy and may be accentuated by infection.

In some cases no obvious stunting is shown, the symptoms being confined to mottling, or one runner only may be affected or one branch only of one runner. It is probable that the stunted forms are primary infections (i.e. they arose from infected vines), the milder forms being secondary (or new) infections.

Field observations of this great variety of symptoms yielded no evidence whether one virus or a complex is concerned. In any one locality, the symptoms shown by any one sweet potato variety appeared remarkably uniform except for differences in degree of severity. This suggested that differences in symptoms might be merely a reflection of varietal differences. That different varieties react differently to the same virus has now been shown. Two viruses which looked dissimilar, one being on the variety *Buwala* and the other on *Sakolya*, were brought to Muguga from Kawanda. Each of these was transmitted to five plants each of eight varieties. The ten grafted plants of each variety developed

identical symptoms suggesting that the two viruses were identical. Further, no two varieties developed symptoms identical with each other. Among the eight varieties used, all the symptoms mentioned above were found. Additional evidence was obtained from a variety, popular near Moshi, whose leaves were often frilled and distorted but which showed no other symptoms that might be due to virus attack. It was thought that these symptoms might be of genetic origin but when scions from affected plants were grafted to healthy stocks of other sweet potato varieties, these developed a number of symptoms including a bright yellow mottle. It seems generally true to say that mottling is more common in the broad-leaf varieties and leaf-distortion in the narrow-leaf varieties, although either type of sweet potato may show either form of symptom.

That growing conditions may also affect symptom expression is shown by the change which often occurs when cuttings or roots from infected plants are brought from the field to the glass-house. It has often happened that after a few weeks their condition no longer agreed with the descriptions written when they were collected. Many more experiments of the kind described and also using an insect vector, if one can be found, must be done before it will be possible to say whether one or more viruses or virus strains are concerned.

Mention might here be made of several other conditions which from their appearance might be confused with virus infections.

A slight leaf-rolling is fairly frequently seen, but this is probably a varietal reaction to certain physiological conditions. In one variety only, in the Aberdare mountains, a severe leaf-rolling, reminiscent of the leaf-roll disease of the Irish potato, was seen. So far, all attempts to transmit this by grafting have failed and its cause is unknown. It appears to be of little importance.

Certain variegations and leaf distortions seen in the sweet potato may be of genetic origin. All attempts to transmit a bright yellow variegation that was very common in one variety only, grown in the Teita Hills, have failed. It seems therefore improbable that this condition is infectious. Great leaf-distortion has occurred in some plants grown from seed, but all attempts to transmit the condition by grafting have failed, although it looked identical with the leaf-distorting virus found near Moshi and mentioned above.

In some districts, plants suffer severely from attack by thrips. Plants are stunted and their leaves distorted. These insects feed chiefly from beside the veins, removing the cuticle and producing a superficial resemblance to the vein clearing caused by some viruses in some plants. This type of damage was seen on an occasional plant in many districts, but it was particularly severe in February 1952 on the coastal plain around Tanga and Mombasa. (No other comparable district has been visited.) In these areas it was common to find every plant in a plot attacked and the resultant loss must be considerable.

Some varieties that are normally hairless or nearly so may become so hairy that their colour appears white or grey. This abnormality was not found on the coastal plain but was widespread in all the other areas

visited and was often very serious. It is probably not due to a virus; its cause is at present under investigation and will be dealt with in a subsequent paper.

*Distribution and Spread*

During the course of several tours, undertaken to become familiar with the disease in the field before starting to study it under glass-house conditions, some interesting observations were made on the distribution

FIG. 1

and natural spread of the disease. Parts of the three East African Territories as well as the mountainous eastern part of Belgian Congo and Ruanda-Urundi were visited. The routes taken are shown on the sketch-map. Agricultural departments and I.N.E.A.C.[1] stations were visited, and since the journeys were all made by road, every opportunity was taken of examining native crops passed on the way. In all more than 150 plots were examined.

Previous records of the disease remarked only on its presence and did not state the more important fact as to whether or not it was spreading. Disease could easily be present in a vegetatively propagated crop, due to infected vines being brought from other districts, but not be spreading naturally. New varieties may be imported for trial by experimental stations, or the sweet potato may not be used by the tribe indigenous to a particular district, but may be brought in by members of other tribes who have moved to the district. It is probable that the

[1] Institut national pour l'Étude agronomique au Congo Belge.

disease is spread in the field by insects; and, unless the appropriate vector is present, increase in the disease will be very slight, being confined to propagation from infected vines. On these tours, the amount of spread was estimated by observation of the relative numbers of presumed primary and secondary infections. On the first tour made, which included parts of Uganda, Belgian Congo, and Ruanda-Urundi, it soon became evident that the virus could be present but be showing no natural spread. In every case where this was so it was found that the sweet potatoes had been recently brought from another district where the disease was prevalent.

In the west of Uganda the disease was often severe and spreading rapidly. However, at the Experimental Station at Kachwakano (near Kabale), which is about 7,000 ft. above sea-level, spread was very slight, although at Mwisi, only a mile or so away but about 1,500 ft. lower, the disease was severe and spreading rapidly. Near the west shores of Lake Kivu, at about 5,000 ft., the disease was very serious indeed, although when in a very short distance one rose to about 6,500 ft. few diseased plants were seen and the spread appeared to be slight. In the valley stretching to the north of Lake Tanganyika although some introduced disease was seen at 3,000 ft., no secondary infections could be seen. On the plains near the NE. shores of this lake at about 2,000 ft. no virus disease was seen and, in the recollection of the Agricultural Officer who had been there since 1938, it had never occurred there. In Ruanda-Urundi the disease was bad at 5,000 ft., whilst at 6,500 ft. there was little spread. Below Kigale and near Rutshuru it was bad, and beside the undulating road from Butembo to Beni it was spreading rapidly in the higher regions traversed but was absent from the lower. In the Ituri Forest, sweet potatoes lined the road-side for many miles and seemed entirely free from virus disease. The disease again became very severe and rapidly spreading in the rising country nearing Nioka. In the northern and eastern parts of Uganda no virus disease was seen until the route rose into the foot-hills of Mount Elgon. As it rose from 4,000 to 5,000 ft. the number of infected plants increased markedly.

The observations summarized above clearly indicated that in these territories the amount of spread of the disease was invariably very great between 4,000 and 5,500 ft. above sea-level. Above 6,000 ft. it was relatively slight and between 2,000 ft. (the lowest level then visited) and 3,500 ft. no natural spread occurred. In all parts of these territories visited which lie between the critical levels of 4,000 and 5,500 ft., the disease was serious.

Further observations were made in Kenya and Tanganyika, but although the disease was widespread it never reached very great proportions except in a few places, such as Kisumu. Disease appeared not to be present on the coastal plain although owing to the devastation caused by thrips it was impossible to be quite certain. From information given me by the Department of Agriculture there, it seems not to be present in the Protectorate of Zanzibar, where no land rises to more than 400 ft. above sea-level. In the hills in Kenya and Tanganyika the degree of spread seemed to be determined by altitude but the critical

levels were not, of necessity, the same as farther west. In the Aberdare mountains, for example, they seemed to be about 1,000 ft. higher. Owing to the smaller amount of disease present, results were less clear cut but nothing was seen to conflict with the observations made on spread and the conclusions drawn from tours farther west.

It is not suggested that altitude has any direct effect on the disease but rather on its vector. It is probable that the disease is spread in the field by some sucking insect, although what insect is responsible is not yet known. It is suggested that it is one which dislikes the hot humid climate of the coast and the shores of the lower lakes. At about 5,000 ft. the insect seems to breed and move freely, and in the higher, cooler altitudes it is either present in smaller numbers or its movement may be restricted by climatic conditions. The differences in the critical levels in different districts would thus be easily accounted for. They would vary with the topographical formation of the land and might be expected to vary from season to season.

*Conclusion.*—Although the widespread devastation which was feared in 1944 has not occurred, a complacent attitude must not be adopted; though in much of East Africa the disease has not yet done severe damage, it is almost everywhere present in a few plants ready to act as foci of infection should conditions in any season happen to favour the vector. My attention was recently drawn to one place within 20 miles of Nairobi where this seems to have occurred. Eighteen months ago, vines of a tuberless cattle-feeding variety were imported from another district. Soon after planting a few plants were seen to look abnormal but the significance was not realized. Now, in this plot, it is almost impossible to find any plants which even look healthy.

Ultimate control of such a disease in a native crop must obviously lie in the production of resistant varieties. Before this can be satisfactorily done, a fundamental knowledge of the disease is necessary. We must know whether one or more viruses are concerned; the insect vector or vectors must be found; a search must be made for alternative hosts of the disease and also for immune related species. Work on these problems is starting at Muguga.

*Acknowledgements.*—My thanks are due to the many officers of the Agricultural departments and I.N.E.A.C. stations who assisted me as guides, with much information gained from their experience, and with much hospitality on these tours. I shall always be grateful to receive any information on the incidence of the disease that they may consider of interest.

## REFERENCES

1. H. R. Rosen, Ark. Agric. Expt. St., 1920, Bull. No. 167.
2. R. Stayaert, Publ. I.N.E.A.C., 1947, 677.
3. C. G. Hansford, E. Afr. Agric. J., 1944, **10**, 126.
4. G. Wallace, Myc. Circ., Dept. Agric. T.T., 1945, 17.
5. —— Ann. Rept. Dept. Agric. T.T. for 1945, 1948, 144.
6. R. F. W. Nichols, Rept. for 1946 E. A. Agric. Res. Inst. Amani, 1947, 13.
7. R. M. Nattrass, Personal communication.

(*Received November 20, 1952*)

# A SELF-CLEANING, MINIATURE THRESHER

C. BARCLAY[1]

THE machine described in this note was constructed and used for threshing many thousands of samples, each consisting of a few handfuls of ears of corn or pods of peas. Such samples can be threshed, the grain weighed and rebagged, at the rate of one or more per minute, with a suitable arrangement of thresher and balance.

The machine was constructed during the war from a second-hand vacuum cleaner. The housing A (Fig. 1), containing a 190-watt electric

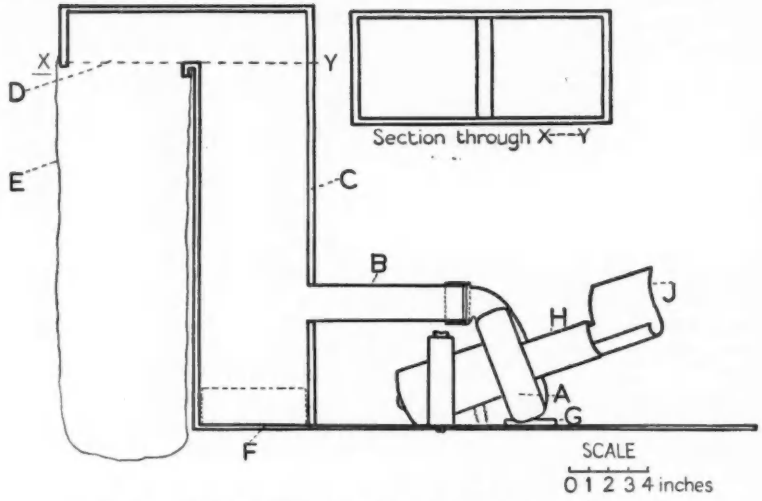



FIG. 1. Original model of miniature thresher shown in section. For description see text.

motor, with a six-bladed fan mounted on its shaft, is provided with an intake tube H, long enough to prevent fingers reaching the blades, and a detachable, inclined feeding-platform J, both cut from tins. A pad of rubber G, beneath the fan assembly, reduces the resonance.

The exit from the housing is provided with a horizontal tube B, sealed into an aperture in a vertical, wooden separatory column C. A short length of cycle-tube is used to seal the joint between B and the fan exit. The column makes two right-angled turns at the top and ends in an exit D, around which a sack E is hung. Below the inlet into the column is a drawer F, to catch the grain. This drawer must be a good fit to prevent blowing out and must be so constructed, preferably countersunk, as to avoid ledges or cracks where grain can lodge.

[1] Agricultural Research Council, late of East Malling Research Station and Plant Breeding Institute, Cambridge.

[Empire Journ. of Exper. Agric., Vol. 21, No. 83, 1953.]

The samples are poured slowly from the bag into the sloping trough J. The ears or pods are sucked into the fan in A, where the grain is knocked out, and the mixed grain and chaff pass along the horizontal tube B into the separatory column C, down which the grain falls into the drawer F, while the chaff is carried by the stream of air up the column and over into the sack E.

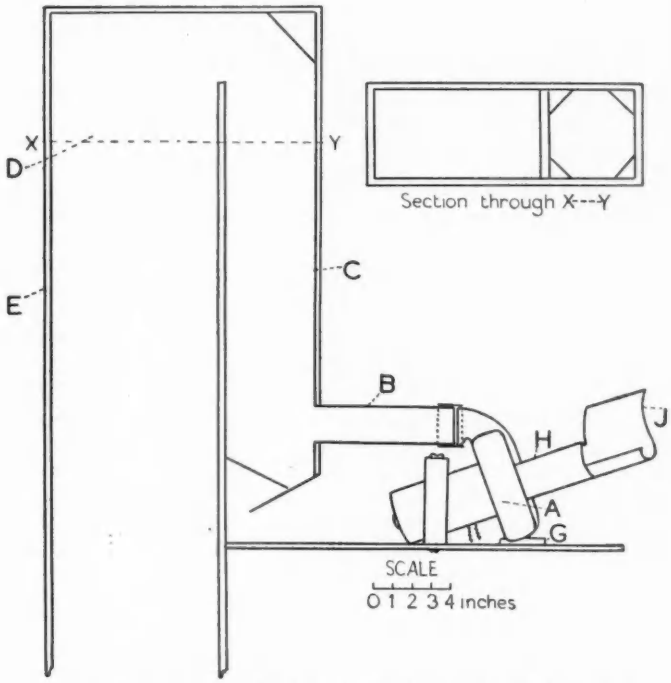



FIG. 2. Improved model of miniature thresher shown in section. For description see text.

For threshing small sheaves, the ears are fed into the fan one by one, the straw being held and withdrawn to prevent jamming. Odd bits of straw are dealt with satisfactorily, but the machine will not deal with straw in quantity.

As originally built in 1945 (Fig. 1), dust escapes through the sack. This can be prevented by ensuring a less rapid expulsion of the air, and by having the opening well below the top of a large container, or tea-chest, in which the chaff is collected, and by covering the top of this around the column with muslin.

An improvement, which has recently been tested in full-size model, using manilla board for the expansion chamber (Fig. 2), consists in having an octagonal column with sloping top and bottom, to avoid

right angles, where eddies might arise. This model permits continuous operation, because the grain pours out of the column, instead of into a drawer. The elimination of eddies ensures satisfactory winnowing at a lower fan-speed, thus reducing both the risk of damage to the grain and the tendency for dust to escape. The air speed is reduced in stages by increasing the area of cross-section, which is about 3 sq. in. in the tube B, 19 in the separatory column C, and 44 in the downcast. Further, the downcast is carried well into the tea-chest and the opening of the tea-chest is covered with cheese-cloth. Chaff must not be allowed to accumulate near the opening of the downcast.

The efficiency of threshing is easily checked by putting a tray under the downcast and examining the ears and chaff that emerge. Damage to the embryo has been reported from a machine reputed to be a copy of the original; but the writer has had no trouble, provided that the voltage is reduced by a suitable resistance (e.g. lamps) so that the speed of the fan is just sufficient to carry off the ears and chaff. This is usually ample for threshing. Normally the motor revolves at about 9,000 revolutions per minute. At least 6,000 seem to be required for wheat, the actual speed depending largely on its dryness. Peas require gentle treatment to avoid splitting.

The writer is much indebted to Dr. W. A. Roach, who helped build the original; to Miss M. E. M. Bland for preliminary work on the improved model; to Miss M. E. Bunyard for preparing the manuscript and diagrams; and to the Agricultural Research Council who financed the work that made the thresher necessary.

*Summary*—A miniature thresher is described that deals expeditiously with samples or single ears, or pods, and needs no cleaning out between samples. It is constructed from a vacuum cleaner.

(*Received December 26, 1952*)

# CASTRATION OF LAMBS: COMPARISON OF THE RUBBER-RING LIGATURE AND CRUSHING TECHNIQUES

J. R. BARROWMAN, T. G. BOAZ, AND K. G. TOWERS

(*Department of Agriculture, University of Leeds*)

WITH PLATES 8, 9

THE sheep flock on the Leeds University farm was established in September 1950 by the purchase of fifty Half-bred (Border Leicester × Cheviot) ewe lambs at Lockerbie and forty-five Clun Forest ewe lambs from three different flocks in Herefordshire and Shropshire. The main object was to extend the comparison of breeds for fat-lamb production which had been carried out at Askham Bryan for a long period until this farm was relinquished in 1946 [1, 2]. A study was also to be made of the practice of breeding from ewe lambs and of the extent to which variability of the lamb crop could be attributed to different rams used for mating. The general policy on the University farm is to use the sheep flock largely as scavengers, utilizing leys, sugar-beet tops, and other available root crops. The ewes are crossed with Suffolk rams and the lambs are sold fat off the ewes at an average live-weight of about 80 lb.

Half the ewe lambs of each breed were mated in 1950 and the first lamb crop was obtained in the spring of 1951. A suspected risk of loss from tetanus led to the trial of bloodless methods of castration of the ram lambs, and in that year rubber-ring ligatures were used on one or two lambs, the majority being castrated by the Burdizzo crushing method. In 1952 these two methods were compared, using all available male lambs; and this report describes the investigation. The rubber-ring ligatures were effected by means of the Elastrator equipment.

The Burdizzo crushing method of castration has been in use in this country for some years. Comparisons of the method with the knife method of castration have been carried out by Fraser [3], Garner and Sanders [4], and Biggar [5]. The rubber-ring technique, on the other hand, has only recently been introduced though it has been extensively used in New Zealand, where several million lambs have thus been castrated in recent years [6]. Castration is normally carried out by this technique when the lambs are about 3 weeks of age [7]; this age being considered most suitable from all practical aspects. Practical experience has, however, shown that use of the ring technique may give less pain if carried out within a few days of birth. Walker [6] studied various methods of castration including the rubber-ring method, mainly in respect of their effect upon carcass quality. In all, 350 lambs, born within a 5-day period, were divided into five groups. One group was not castrated, a second was castrated by the ring method at birth, a third by the ring method when the lambs were three weeks old, a fourth by the knife method, and the fifth by the emasculator. Full carcass records

[Empire Journ. of Exper. Agric., Vol. 21, No. 83, 1953.]

were obtained, and the main conclusion was that no harmful effects on carcass quality were associated with the efficient use of rubber rings in castration. In weight, grade, and carcass measurements lambs castrated by rubber rings gave comparable results to those obtained from lambs castrated by the older methods, and no differences could be detected in the proportions of the various parts of the carcass. The average carcass-weight of lambs which were ligatured at 3 weeks was 37·9 lb. and that of emasculated lambs was 37·7 lb. There were approximately sixty-five lambs in each group at the time of slaughter.

### *Lambs used in the Experiment*

TABLE 1. *Composition of the Ewe Flock when the Rams were turned in on October 8, 1951*

| | *Half-bred* | | *Clun* | |
|---|---|---|---|---|
| | *Mated as ewe lambs in 1950 and proved pregnant* | *Mated first as shearlings in 1951* | *Mated as ewe lambs in 1950 and proved pregnant* | *Mated first as shearlings in 1951* |
| Mated to Ram A | 8 | 15 | 4 | 18 |
| Mated to Ram B | 8 | 15 | 4 | 18 |
| Total | 16 | 30 | 8 | 36 |

Lambing began on March 1, 1952 and continued until April 13; 87 lambs were born to the Half-bred ewes, and of these 75 were eventually reared; 79 were born to the Clun ewes, and of these 62 were eventually reared. A full description of the management and lambing results will be given in the report of the main experiment at the conclusion of the fourth year's performance of the ewes. The results to be given now will apply only to the comparison of the two methods of castration.

TABLE 2. *Distribution in Numbers of Lambs reared according to Parentage and Sex*

| | *Half-bred* | | | *Clun* | | | *All Ewes* | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Males* | *Females* | *Total* | *Males* | *Females* | *Total* | *Males* | *Females* | *Total* |
| Ram A . | 23 | 13 | 36 | 16 | 16 | 32 | 39 | 29 | 68 |
| Ram B . | 15 | 24 | 39 | 14 | 16 | 30 | 29 | 40 | 69 |
| Total . | 38 | 37 | 75 | 30 | 32 | 62 | 68 | 69 | 137 |

It will be seen that a total of 68 male lambs were reared: of these 34 were castrated by the Burdizzo method and 34 by rubber-ring ligatures. Allocation to treatment of individual lambs was governed by the statistical requirements of the primary investigation being carried out on the sheep.

TABLE 3. *Allocation of Ram Lambs to Treatments according to Parentage*

| | *Half-bred* | | | *Clun* | | | *Total* | | |
|---|---|---|---|---|---|---|---|---|---|
| | *Ram A* | *Ram B* | *Total* | *Ram A* | *Ram B* | *Total* | *Ram A* | *Ram B* | *Total* |
| Burdizzo . | 10 | 9 | 19 | 8 | 7 | 15 | 18 | 16 | 34 |
| Elastrator . | 13 | 6 | 19 | 8 | 7 | 15 | 21 | 13 | 34 |
| Total . | 23 | 15 | 38 | 16 | 14 | 30 | 39 | 29 | 68 |

Thus, although equal numbers of ram lambs out of both breeds of ewe were castrated by each of the two methods, distribution according to sire was not even, particularly in the Half-bred group. In each case of twin ram lambs, however, the allocation to the method of castration was done at random, so that of each pair one was castrated by the Burdizzo and the other by the Elastrator method. Twelve such pairs were available, eight out of Half-bred ewes, and four out of Clun ewes.

### *Data Recorded*

The following data were recorded in respect of each lamb born:

(*a*) Date and time of birth; (*b*) weight at birth; (*c*) date of castration; (*d*) weekly live-weights from the beginning of May to date of sale; (*e*) date of sale; (*f*) live-weight when sold; (*g*) cold-carcass weight.

In addition, a careful record was made weekly of the condition of the lambs and the effect of castration on the scrotum and testicles, from the date of castration.

### *The Methods used*

(*a*) *Burdizzo*: 34 lambs were castrated by this method and their ages at the time of operation varied from 16–39 days, the majority, however, being between 4 and 5 weeks of age. Each lamb was held by an assistant with the hind-quarters resting on the top rail of the pen, fore and hind legs on each side being grasped by one hand. The scrotum was usually found to be a little too wide to be accommodated completely in the 6 cm. jaws of the instrument although cord-stops were present. The practice was therefore adopted of crushing each cord separately—an assistant holding the cord close to the lateral wall of the scrotum so that the operator could apply the jaws of the instrument a short distance above the epididymis and then crush the cord with certainty. Care was necessary to avoid crushing the nipples of the rudimentary mammary gland of the male, although injury would probably not have caused appreciable trouble. Most lambs were tailed at the same time, but when castration was the only operation carried out no untoward behaviour was exhibited after releasing the lamb. There was a tendency for the lamb to lie quietly for 10 or 20 minutes, but grazing was soon resumed.

(*b*) *Elastrator*: 34 lambs were castrated by this technique and their ages at the time of operation also varied from 16–39 days, the majority

being castrated between 4 and 5 weeks of age. Both groups of lambs were, in fact, castrated at approximately the same age, thus enabling a fair comparison to be made of their subsequent progress. The lamb was held in the same manner as for the Burdizzo technique. The rubber rings were warmed to assist stretching by carrying them in the trouser pocket until required. They were expanded by the instrument and the scrotum manipulated through the aperture, the handles partly released and the ring worked off the metal fingers with the free hand of the operator. Care was taken to keep the ring immediately above the testicles in order to avoid the inclusion of the nipples and abdominal skin in the ligature. The behaviour of the lambs when released is recorded below.

### *Physical Effect of Castration*

(*a*) *Immediate result.*—Lambs castrated by the Burdizzo instrument showed no obvious upset after the operation and the post-operational swelling, which was severe in many cases, often took more than a week to reach a maximum.

In the lambs where rubber rings were applied to the scrotum there was a reaction similar to that seen in lambs 'tailed' by the ligature method. After the ring had been positioned and the lamb put on the ground it walked a few steps away from the operators and then fell sideways to the ground (Plate 8, fig. 1). It would then almost immediately commence to contort its body, often nosing the scrotal region in a perfunctory manner and then passing through five or ten minutes of great uneasiness. During this period the lamb would walk a few steps, fall down, sometimes sideways, sometimes backwards, and when on the ground would occasionally roll completely from one side to the other. No bleating was observed apart from a little answer to the call of the ewes still in the pen. After 20 min. the lamb would be lying perfectly quietly, and apparently in comfort, and after 30 min. most lambs had started to graze and no more evidence of discomfort was shown.

(*b*) *Weekly clinical inspections.*—The most noteworthy change induced by castration with the Burdizzo was the swelling, often asymmetrical, to be seen in the scrotum and testicles in the majority of the lambs. In only one of the 34 subjects was there an appreciable testicular atrophy present at the time of the first weekly inspection and if swelling had first occurred it was not detected. In 17 lambs at this time there was testicular swelling to twice and three times the normal size and in the following 2 weeks another 8 lambs were first noted to have developed enlargement. The testicles as well as being enlarged were quite hard to the touch. The scrotum itself was enlarged and in 18 cases in the first fortnight after operation there was a puffy, oedematous swelling present. A few lambs continued to develop scrotal oedema up to 7 weeks after operation. A diminution in the size of the testicles was evident in 9 lambs 3 weeks after operation, 6 more at 4 weeks, 8 at 5 weeks, 6 at 6 weeks, 3 at 7 weeks, and 1 at 8 weeks. Some of the gonads were still enlarged at the time of slaughter. Scrotal atrophy was present in 5 lambs after 3

weeks, 6 more at 4 weeks, 7 at 5, 3 at 6, and 2 at 8 weeks. The gross distortion of the tissues after castration by this method suggests that it should not be regarded as ideal. In one lamb the wool covering the scrotum became altered and finally tended to slough off, presumably from interference with skin nutrition caused by the obliteration of cutaneous vessels. This dead appearance of the wool has been seen before and probably will be more likely to occur when the instrument is applied across the whole width of the scrotum.

In the lambs which were castrated by the Elastrator ring ligature a considerable number developed an obvious break in skin continuity immediately above the ring. This wound was coated with a thin film of greenish pus which was overlying healthy granulation tissue. Such an appearance was first noted in one lamb at the first weekly inspection after castration. At 2 weeks 13 lambs were affected, at 3 weeks 8 more, and at 4 weeks 3 lambs were showing wounds with pus just above the ring (i.e. in all 70 per cent.). In no case was the dirty wound observed for more than a fortnight, a clean healthy wound soon developing with a perfectly dry scab on top. The scrotum was observed to have fallen off the lambs in all cases at 6 weeks after castration. It was common to find the hard and shrivelled remnant adhering by means of wool caught in the ring with the wound well on its way to complete healing (Plate 9, fig. 2). The following times, however, indicate when the skin and spermatic cord had separated completely: 6 lambs had lost their scrotum at the 3rd weekly inspection, 10 at the 4th week, 11 at the 5th, and the remaining 7 by the 6th week. There was no swelling of dependent parts and the testicles diminished in size steadily from the time the ring was applied (Plate 9, fig. 3) until at 4 or 5 weeks they were not recognizable in the small, hard scrotal remnant. The complete healing of the wound, that is the restoration of skin continuity, was present in 3 lambs after 5 weeks from operating, in 12 more at 6 weeks, 13 at 7 weeks, 4 at 8 weeks, 1 at 9 weeks, and the remaining lamb at 10 weeks (Plate 9, fig. 4). After slaughter no abnormality was found, in no case had the pus been more than superficial, but the weak nature of the cutaneous scar was noted when the hide was removed on skinning. There was some liability for a slight tear to develop at the healed site of operation, but this is not a valuable part of the hide and the lesion can be disregarded. One of the lambs suffered from blow-fly strike on the breach. This was apparently not related to the castration although a wound containing pus was present. The lamb had diarrhoea at the time and this was probably responsible.

### *Performance of the Lambs*

The data recorded have been examined to find out if any difference in subsequent performance of the lambs resulted from the different methods of castration. A summary of the data based on all lambs castrated is given in Table 10 and full details of the results from 12 pairs of twin lambs are given in Table 11. A note on the statistical analysis of data from the twin lambs is given in the appendix.

(*a*) *Birth-weight*

TABLE 4. *Birth-weight of Lambs*

| | *Half-bred* | | *Clun* | | *All lambs* | |
|---|---|---|---|---|---|---|
| | *No.* | *Weight (lb.)* | *No.* | *Weight (lb.)* | *No.* | *Weight (lb.)* |
| Burdizzo | 19 | 10·9 | 15 | 9·9 | 34 | 10·4 |
| Elastrator | 19 | 10·9 | 15 | 9·4 | 34 | 10·3 |

On average there was no difference between the two groups.

In the case of the twelve pairs of twin lambs a difference in birth-weight was present, those castrated by the Burdizzo method being 10·35 lb. at birth and those by the Elastrator 10·79 lb.

(*b*) *Sale-weight*

TABLE 5. *Sale-weight of Lambs*

| | *Half-bred* | | *Clun* | | *All lambs* | |
|---|---|---|---|---|---|---|
| | *No.* | *Weight (lb.)* | *No.* | *Weight (lb.)* | *No.* | *Weight (lb.)* |
| Burdizzo | 19 | 82·9 | 15 | 81·9 | 34 | 82·5 |
| Elastrator | 19 | 83·4 | 15 | 81·4 | 34 | 82·5 |

On average all groups of lambs were sold at the same live-weight.

(*c*) *Dressing Percentage*

TABLE 6. *Dressing Percentage of Lambs*

| | *Half-bred* | | *Clun* | | *All lambs* | |
|---|---|---|---|---|---|---|
| | *No.* | % | *No.* | % | *No.* | % |
| Burdizzo | 19 | 46·8 | 15 | 46·3 | 34 | 46·6 |
| Elastrator | 19 | 46·0 | 15 | 45·3 | 34 | 45·7 |

There is a very slight indication that lambs castrated by the Elastrator dressed out at a lower rate than those castrated by the Burdizzo. In the case of the pairs of twins the results were: Burdizzo: D.P. 45·8 per cent.; Elastrator: D.P. 44·9 per cent., giving a difference which was not significant statistically.

(*d*) *Age Sold*

TABLE 7. *Age of Lambs when Sold*

| | *Half-bred* | | *Clun* | | *All lambs* | |
|---|---|---|---|---|---|---|
| | *No.* | *Age (days)* | *No.* | *Age (days)* | *No.* | *Age (days)* |
| Burdizzo | 19 | 92·7 | 19 | 100·4 | 34 | 96·1 |
| Elastrator | 15 | 97·3 | 15 | 102·9 | 34 | 99·7 |

This result slightly favours the lambs castrated by the Burdizzo and is supported by the figures from the twins, where the difference was 7 days, though again not statistically significant.

(*e*) *Daily live-weight gain* was calculated by dividing the gain in weight from birth to date of sale by the age in days when sold.

TABLE 8. *Daily Live-weight Gain of Lambs*

| | *Half-bred* | | *Clun* | | *All lambs* | |
|---|---|---|---|---|---|---|
| | *No.* | *L.W.G. (lb.)* | *No.* | *L.W.G. (lb.)* | *No.* | *L.W.G. (lb.)* |
| Burdizzo | 19 | 0·78 | 15 | 0·73 | 34 | 0·76 |
| Elastrator | 19 | 0·75 | 15 | 0·72 | 34 | 0·74 |

The difference between the two groups is very small, and this is supported by the figures from the pairs of twins, 0·75 lb. per day by the Burdizzo method and 0·71 lb. per day by the Elastrator.

In a further attempt to obtain an expression of the difference, all male lambs born and reared as twins were grouped with the results given in Table 9.

TABLE 9. *Live-weight Gain per Day of all Male Lambs reared as Twins*

| | *Half-bred* | | *Clun* | | *All lambs* | |
|---|---|---|---|---|---|---|
| | *No.* | *L.W.G. (lb.)* | *No.* | *L.W.G. (lb.)* | *No.* | *L.W.G. (lb.)* |
| Burdizzo | 13 | 0·85 | 11 | 0·70 | 24 | 0·78 |
| Elastrator | 11 | 0·77 | 10 | 0·66 | 21 | 0·72 |

This grouping has the merit of leaving out those born as singles, triplets, and quadruplets. The difference is seen to be more pronounced, being of the order of over ½ lb. per week in lambs out of the Half-bred ewes.

Another way of ruling out certain extraneous influences is to calculate the actual gain in weight over the same period of days. For the twelve pairs of twins, the weight of the twins on a common date was tabulated and a statistical analysis carried out on the resulting data. In this case lambs castrated by the Burdizzo method had a greater weight by 3·27 lb. than the respective twins castrated by the Elastrator, but this difference was not significant statistically, despite a low error of 7·4 per cent.

(*f*) *Carcass quality*.—It was not possible to examine carcasses of the lambs in detail. All lambs were graded alive at the collecting centre in the usual way, and payment made on the estimated carcass-weight. At the abattoir where the lambs were slaughtered and the carcasses weighed, all carcasses were graded as satisfactory, no distinction being made.

## *Discussion*

The main practical result arising from the investigation is that no significant difference was found in the progress and performance of

TABLE 10. *Summary of Results: All Male Lambs*

A. *Lambs out of Half-bred Ewes*

| | *Total no. of lambs* | *Nos. of lambs reared as* | | | *Av. wt. at birth (lb.)* | *Av. age at castration (days)* | *Av. live-wt. when sold (lb.)* | *Av. carcass-wt. (lb.)* | *Av. dressing percentage* | *Av. age when sold (days)* | *Av. gain in live-wt. (lb.)* | *Live-wt. gain per day (lb.)* | *Av. carcass-wt. per day of age (lb.)* | *Av. days from castration to sale (days)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Singles* | *Twins* | *Triplets* | | | | | | | | | | |
| Burdizzo | 19 | 2 | 15 | 2 | 10·9 | 31 | 83 | 39 | 47 | 93 | 72 | 0·78 | 0·42 | 61 |
| Elastrator | 19 | 3 | 14 | 2 | 10·9 | 31 | 83½ | 38½ | 46 | 97 | 72½ | 0·76 | 0·41 | 67 |

B. *Lambs out of Clun Ewes*

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Burdizzo | 15 | 3 | 11 | 1 | 9·9 | 31 | 82 | 38 | 46 | 100 | 72 | 0·73 | 0·39 | 69 |
| Elastrator | 15 | 4 | 10 | 1 | 9·4 | 29 | 81½ | 37 | 45 | 103 | 72 | 0·72 | 0·37 | 73 |

C. *All Lambs*

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Burdizzo | 34 | 5 | 26 | 3 | 10·4 | 31 | 82½ | 38½ | 46½ | 96 | 72 | 0·76 | 0·41 | 65 |
| Elastrator | 34 | 7 | 24 | 3 | 10·3 | 30 | 82½ | 37¾ | 45¾ | 99½ | 72 | 0·74 | 0·39 | 70 |

Note: Results approximated to nearest ½ lb. or half-day in most cases

lambs subsequent to castration at ages of 3 to 5 weeks by the 'bloodless' (Burdizzo) method on the one hand and by the rubber-ring ligature (Elastrator) method on the other. The lambs castrated by the Burdizzo method reached an equivalent sale-weight 4 days earlier on average than those castrated by the Elastrator despite a slightly lower average weight when born. For the 12 comparable sets of twins the difference was in fact 7 days, but was not statistically significant. This result was reflected in the slightly greater gain per day of the Burdizzo group, which also had a slightly greater carcass-weight for age.

From the description given on page 197 it is clear that the rubber-ring ligature is not a safe means of eliminating the chance of infection, particularly anaerobic soil infections, since it is accompanied by an open wound in 70 per cent. of the animals. The wound, it is true, always had healthy granulation tissue in its depth, and this tissue is well known to be resistant, but the possibility of penetration of infection through a crack produced by trauma must not be disregarded. The age of the lambs at which the rubber-ring ligature is applied may have some significance in this respect. On the evidence presented in this report it would appear that the use of rubber-ring ligatures as a method of castrating lambs from 3–5 weeks of age has a certain advantage over the crushing method in ease of operation and effectiveness, but seemingly does involve the animal in more discomfort immediately after the operation and also, to a limited extent, retards its subsequent progress. It should be emphasized that according to other experience the discomfort described may be avoided by castration at an early age (within a week or two of birth). In future work this aspect will be investigated and a more precise comparison between the two methods will be obtained by weighing the lambs at the time of castration.

## *Summary*

1. An investigation carried out on the Leeds University farm compares the rubber-ring ligature and crushing methods of castrating lambs aged from 3–5 weeks, subsequently sold as fat lambs at a live-weight of approximately 80 lb.

2. Thirty-four lambs were castrated by each method, the lambs being out of Half-bred and Clun ewes, sired by Suffolk rams. The physical effects of castration were recorded and clinical inspections made. The performance of the lambs was measured by weighing at weekly intervals and recording the live- and dead-weights when sold. The results from twelve sets of twins were examined statistically.

3. On average, lambs castrated by the Burdizzo method required 4 days less to reach slaughter-weight from time of birth, and gave slightly heavier carcasses (by $\frac{3}{4}$ lb.). These differences were not statistically significant.

*Acknowledgements.*—The authors record their appreciation of the work carried out by Mr. L. E. Croft, who was responsible for much of the detailed weighing and recording of the progress of the lambs on the University farm, and they also thank Mr. D. L. Wynn, area slaughter-

TABLE 10. *Summary of Results: All Male Lambs*

A. *Lambs out of Half-bred Ewes*

| | *Total no. of lambs* | *Nos. of lambs reared as* | | | *Av. wt. at birth (lb.)* | *Av. age at castration (days)* | *Av. live-wt. when sold (lb.)* | *Av. carcass-wt. (lb.)* | *Av. dressing percentage* | *Av. age when sold (days)* | *Av. gain in live-wt. (lb.)* | *Live-wt. gain per day (lb.)* | *Av. carcass-wt. per day of age (lb.)* | *Av. days from castration to sale (days)* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | *Singles* | *Twins* | *Triplets* | | | | | | | | | | |
| Burdizzo | 19 | 2 | 15 | 2 | 10·9 | 31 | 83 | 39 | 47 | 93 | 72 | 0·78 | 0·42 | 61 |
| Elastrator | 19 | 3 | 14 | 2 | 10·9 | 31 | 83½ | 38½ | 46 | 97 | 72½ | 0·76 | 0·41 | 67 |

B. *Lambs out of Clun Ewes*

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Burdizzo | 15 | 3 | 11 | 1 | 9·9 | 31 | 82 | 38 | 46 | 100 | 72 | 0·73 | 0·39 | 69 |
| Elastrator | 15 | 4 | 10 | 1 | 9·4 | 29 | 81½ | 37 | 45 | 103 | 72 | 0·72 | 0·37 | 73 |

C. *All Lambs*

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Burdizzo | 34 | 5 | 26 | 3 | 10·4 | 31 | 82½ | 38½ | 46½ | 96 | 72 | 0·76 | 0·41 | 65 |
| Elastrator | 34 | 7 | 24 | 3 | 10·3 | 30 | 82½ | 37¾ | 45¾ | 99½ | 72 | 0·74 | 0·39 | 70 |

Note: Results approximated to nearest ½ lb. or half-day in most cases

lambs subsequent to castration at ages of 3 to 5 weeks by the 'bloodless' (Burdizzo) method on the one hand and by the rubber-ring ligature (Elastrator) method on the other. The lambs castrated by the Burdizzo method reached an equivalent sale-weight 4 days earlier on average than those castrated by the Elastrator despite a slightly lower average weight when born. For the 12 comparable sets of twins the difference was in fact 7 days, but was not statistically significant. This result was reflected in the slightly greater gain per day of the Burdizzo group, which also had a slightly greater carcass-weight for age.

From the description given on page 197 it is clear that the rubber-ring ligature is not a safe means of eliminating the chance of infection, particularly anaerobic soil infections, since it is accompanied by an open wound in 70 per cent. of the animals. The wound, it is true, always had healthy granulation tissue in its depth, and this tissue is well known to be resistant, but the possibility of penetration of infection through a crack produced by trauma must not be disregarded. The age of the lambs at which the rubber-ring ligature is applied may have some significance in this respect. On the evidence presented in this report it would appear that the use of rubber-ring ligatures as a method of castrating lambs from 3–5 weeks of age has a certain advantage over the crushing method in ease of operation and effectiveness, but seemingly does involve the animal in more discomfort immediately after the operation and also, to a limited extent, retards its subsequent progress. It should be emphasized that according to other experience the discomfort described may be avoided by castration at an early age (within a week or two of birth). In future work this aspect will be investigated and a more precise comparison between the two methods will be obtained by weighing the lambs at the time of castration.

## *Summary*

1. An investigation carried out on the Leeds University farm compares the rubber-ring ligature and crushing methods of castrating lambs aged from 3–5 weeks, subsequently sold as fat lambs at a live-weight of approximately 80 lb.

2. Thirty-four lambs were castrated by each method, the lambs being out of Half-bred and Clun ewes, sired by Suffolk rams. The physical effects of castration were recorded and clinical inspections made. The performance of the lambs was measured by weighing at weekly intervals and recording the live- and dead-weights when sold. The results from twelve sets of twins were examined statistically.

3. On average, lambs castrated by the Burdizzo method required 4 days less to reach slaughter-weight from time of birth, and gave slightly heavier carcasses (by $\frac{3}{4}$ lb.). These differences were not statistically significant.

*Acknowledgements.*—The authors record their appreciation of the work carried out by Mr. L. E. Croft, who was responsible for much of the detailed weighing and recording of the progress of the lambs on the University farm, and they also thank Mr. D. L. Wynn, area slaughter-

TABLE 11. *Comparison of Results based on Data from Twin Lambs*

| *No. of pair* | *Dam* | *Sire* | *Date of castration* | *Age when castrated (days)* | *Wt. at birth* | | *Sale-wt.* | | *Carcass-wt.* | | *Dressing percentage* | | *Age sold* | | *Live-wt. gain per day* | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | B (*lb.*) | E (*lb.*) | B (*lb.*) | E (*lb.*) | B (*lb.*) | E (*lb.*) | B | E | B (*days*) | E (*days*) | B (*lb.*) | E (*lb.*) |
| 1 | Half-Bred | Ram A | 25/3 | 20 | 8·25 | 10·25 | 81 | 89 | 37 | 41 | 45·7 | 46·1 | 82 | 96 | 0·89 | 0·82 |
| 2 | Half-bred | Ram A | 29/4 | 33 | 10·5 | 11·75 | 82 | 83 | 39 | 41 | 47·6 | 49·4 | 81 | 81 | 0·88 | 0·88 |
| 3 | Half-bred | Ram B | 22/4 | 36 | 11·5 | 10·75 | 77 | 86 | 37 | 40 | 48·1 | 46·5 | 91 | 112 | 0·72 | 0·67 |
| 4 | Half-bred | Ram A | 25/3 | 21 | 12·0 | 12·50 | 78 | 80 | 33 | 34 | 42·3 | 42·5 | 104 | 111 | 0·63 | 0·61 |
| 5 | Half-bred | Ram A | 8/4 | 29 | 8·5 | 12·50 | 84 | 82 | 40 | 38 | 47·6 | 46·3 | 98 | 77 | 0·77 | 0·90 |
| 6 | Half-bred | Ram A | 22/4 | 32 | 10·25 | 7·75 | 80 | 84 | 37 | 37 | 46·3 | 44·0 | 94 | 108 | 0·74 | 0·71 |
| 7 | Half-bred | Ram B | 22/4 | 33 | 9·75 | 12·75 | 82 | 86 | 41 | 38 | 50·0 | 44·2 | 95 | 109 | 0·76 | 0·67 |
| 8 | Half-bred | Ram A | 22/4 | 30 | 13·00 | 12·75 | 85 | 83 | 34 | 36 | 40·0 | 43·4 | 106 | 92 | 0·68 | 0·76 |
| 9 | Clun | Ram A | 29/4 | 16 | 10·25 | 9·25 | 84 | 78 | 38 | 34 | 45·2 | 43·6 | 92 | 106 | 0·80 | 0·65 |
| 10 | Clun | Ram B | 22/4 | 32 | 9·75 | 8·25 | 85 | 84 | 37 | 40 | 43·5 | 47·6 | 108 | 108 | 0·70 | 0·70 |
| 11 | Clun | Ram A | 22/4 | 32 | 9·50 | 10·00 | 83 | 72 | 40 | 30 | 48·2 | 41·7 | 94 | 129 | 0·77 | 0·48 |
| 12 | Clun | Ram B | 29/4 | 28 | 11·00 | 11·00 | 82 | 81 | 37 | 35 | 45·1 | 43·2 | 104 | 104 | 0·68 | 0·67 |
| Total | | | | 342 | 124·25 | 129·5 | 983 | 988 | 450 | 444 | 549·6 | 538·5 | 1,149 | 1,233 | 9·02 | 8·52 |
| Mean | | | | 28·5 | 10·35 | 10·79 | 81·9 | 82·3 | 37·5 | 37·0 | 45·8 | 44·9 | 96 | 103 | 0·75 | 0·71 |

B = Lambs castrated by Burdizzo method. E = Lambs castrated by Elastrator method.

FIG. 1. Symptoms shown by lambs immediately after castration. The lambs were also docked with rubber ligatures.

FIG. 2. Scrotal separation in this lamb was complete in 14 days after the operation.

FIG. 3. Scrotal atrophy 14 days after application of the rubber ring.

FIG. 4. Complete healing at 6 weeks.

house agent, Ministry of Food, and Mr. F. C. Reid, slaughter-house manager, Leeds City abattoir, for their co-operation in enabling records of carcass-weights to be obtained at the Leeds Corporation abattoir.

## REFERENCES

1. T. G. Boaz, T. L. Bywater, and G. C. A. Robertson, 1947, Bulletin No. 210 (Leeds University).
2. —— —— —— 1948, Bulletin No. 211 (Leeds University).
3. A. Fraser, Sheep Farming, London, 1937.
4. F. H. Garner and H. G. Sanders, J. Agric. Sci., 1936, **26**, 297.
5. W. A. Biggar, Scot. J. Agric., 1939, **22**, 143.
6. D. E. Walker, Proceedings of the Ruakura Farmers' Conference Week, N.Z., 1951.
7. D. S. Hendrie. Private communication, 1952.

## APPENDIX

### *Note on Statistical Analysis of Data from Twin Lambs*

1. *Analysis of variance.*—Data have been obtained from 12 pairs of twins, 24 lambs in all. The variation can be apportioned into that due to differences between pairs (breeding, date of birth, &c.), that due to treatments (two), and that due to 'error'. A simple analysis of variance takes the following form.

| *Variation* | *Degrees of Freedom* |
|---|---|
| Pairs . . . . . | 11 |
| Treatments . . . . . | 1 |
| Error . . . . . | 11 |
| Total . . . . . | 23 |

2. *Summary of results*

| | | *Burdizzo* | *Elastrator* | *Mean* | *S.E.* | *Significance* |
|---|---|---|---|---|---|---|
| Age sold | days | 95·75 | 102·75 | 99·25 | 3·11 | insig. |
| | per cent. | 96·5 | 103·5 | 100 | 3·13 | |
| Live-weight gain per day: | lb. | 0·75 | 0·71 | 0·73 | 0·22 | insig. |
| | per cent. | 102·9 | 97·1 | 100 | 3·9 | |
| Carcass-weight produced per day of age | lb. | 0·39 | 0·37 | 0·38 | 0·15 | insig. |
| | per cent. | 103·3 | 96·7 | 100 | 3·9 | |
| Differences in gain in wt. from birth after given period from castration | lb. | 67·5 | 64·2 | 65·8 | 1·41 | insig. |
| | per cent. | 102·6 | 97·6 | 100 | 2·14 | |

(*Received January 23, 1953*)

# THE RESPONSES OF SUGAR-CANE TO FERTILIZERS IN TRINIDAD

G. E. HODNETT

*(Rothamsted Experimental Station, Harpenden, Herts.)*

IN order to gain an over-all picture of the responses of sugar-cane to fertilizers in Trinidad, for determining a general fertilizer policy, all the available results of manurial experiments conducted during the past 20 years have been abstracted and examined [1]. This work constitutes part of an investigation of the responses of tropical crops to fertilizers being carried out under a Colonial Development and Welfare scheme.

Experimental work has been done in many sugar-cane areas over a much longer period than that considered, but modern experimental methods have been mostly employed during the last two decades, so providing data of increased reliability. Carey and Robinson [2] have considered the results of this work in nine countries since the beginning of the century until about 1943. For Trinidad, however, the majority of the experiments considered here have not previously been examined as a whole.

*Data.*—The data were provided by 123 experiments with inorganic fertilizers involving 267 crop results for which the information given included variety and yield of cane, and soil type. In some of the experiments samples of cane had been taken to determine the sugar-content and hence the yield of sugar, but the sampling was not always reliable. Nevertheless, the effect of fertilizers on the sugar percentage of the crops has been examined wherever possible in order to obtain a guide to the ultimate responses to fertilizers in terms of sugar.

The succession of plant-cane and ratoon crops may be termed a *crop series*. Most of the experiments involved a single crop series or part of a series, but as six of them included replanting they were divided into two or three series. The series for which results were available varied in length from one to seven crops. Thus an experiment lasting 6 years from the time of planting might consist of two series: each of plant-canes and first ratoons; or of a single series of plant-canes and first, second, third, and fourth ratoons (the plant-cane crop being reaped in each case in the second year after planting). For about one-third of the series, data were given for the plant-cane results only, whilst of the longer series results were available at least as far as the fourth ratoons. For various reasons, some of the series of results were incomplete; in particular, not all the series of results began with data on plant-canes. In some of these cases this was due to the type of experiment, in which differential treatments were first given to a ratoon crop.

Table 1 shows the distribution of the experiments over the four soil types by which the results were classified and according to their duration, which ranged from 2 years for a single plant-cane crop to twelve or more years for long-term experiments.

[Empire Journ. of Exper. Agric., Vol. 21, No. 83, 1953.]

TABLE 1. *Classification of the Experiments according to Soil Type and Duration*

| | Duration (years) | | | | |
|---|---|---|---|---|---|
| *Soil* | *0–3* | *3–6* | *6–12* | *Over 12* | *Total* |
| I | 11 | 3 | 0 | 0 | 14 |
| II | 43 | 5 | 1 | 1 | 50 |
| III | 26 | 9 | 2 | 4 | 41 |
| III′ | 13 | 5 | 0 | 0 | 18 |
| *Total* | 93 | 22 | 3 | 5 | 123 |

The distribution of the plant-cane and ratoon crops over the four soil types is given in Table 2.

During the war years, owing to labour shortage, a few crops were reaped a year later as 'standovers'. These results have not been used, whereas experiments which received some damage from pests have been included in the analysis as representing a normal hazard.

TABLE 2. *Distribution of the Crops over the Four Soil Types*

| *Soil* | *Plant-canes* | *1st ratoons* | *2nd ratoons* | *3rd ratoons* | *4th ratoons* | *5th ratoons* | *6th ratoons* | *Total* |
|---|---|---|---|---|---|---|---|---|
| I | 14 | 7 | 4 | 1 | 1 | .. | .. | 27 |
| II | 43 | 30 | 11 | 1 | 1 | .. | .. | 86 |
| III | 42 | 35 | 20 | 11 | 6 | 4 | 1 | 119 |
| III′ | 15 | 10 | 5 | 3 | 2 | .. | .. | 35 |
| Total | 114 | 82 | 40 | 16 | 10 | 4 | 1 | 267 |

*Classifications.*—The responses were placed in one of three groups according to the crop: plant-canes, first ratoons, second and other ratoons. The last is an open grouping because of the small numbers of third and higher ratoons (see Table 2). Previous work [2] has suggested a need to examine such responses separately.

The responses to nitrogen, phosphate (as $P_2O_5$), and potash (as $K_2O$) where pen manure had been applied were abstracted separately from those without pen manure.

The classification of soils, according to their moisture relationships, was based on the grouping of Charter [3]:

I. Perennial supply of subsoil seepage water, permitting growth at all seasons.

II. Soils dependent on rainfall for their moisture, so that growth is considerably reduced in a dry season.

III. Soils which experience an accentuated dry season owing to topography and/or texture, and on which the effects of occasional droughts are exaggerated.

III′. Conditions as for III, but the soil derived from calcareous material.

Soils of groups III and III′ belong to the more undulating areas, where erosion affects the moisture characteristics and impairs fertility.

TABLE 3. *Average Yields of Old and New Varieties on the Four Soil Types*

Tons per acre

| *Variety* / *Soil* | *Plants* | | *1st ratoons* | | *2nd ratoons* | |
|---|---|---|---|---|---|---|
| | *Old* | *New* | *Old* | *New* | *Old* | *New* |
| I | 46·4 (10) | 53·6 (4) | 34·0 (7) | .. | 29·9 (3) | .. |
| II | 37·3 (36) | 44·3 (7) | 21·2 (26) | 32·4 (4) | 24·2 (9) | 36·3 (2) |
| III | 35·0 (34) | 45·2 (8) | 22·5 (32) | 27·0 (3) | 18·6 (18) | 29·0 (2) |
| III′ | 44·0 (12) | 52·7 (3) | 28·4 (8) | 26·6 (1) | 20·8 (3) | 29·1 (1) |

Numbers in parentheses are the numbers of experiments on which the means are based.

Soils of groups I and III′ (Table 3) give 25 per cent. higher yields of plant-cane than those of groups II and III, which also have similar average yields. The superiority of the former is also maintained in the succeeding ratoon crops.

The old standard varieties BH 10 (12), Uba, &c., have been replaced within recent years by new ones in the B series, from the Barbados Plant Breeding Station. The responses of old and new varieties of cane were examined separately. The mean yields of old and new varieties in the fertilizer trials are given for the four soil types in Table 3. In only two experiments were varieties (all old) and fertilizers tested together, and so any conclusions concerning the respective responses of old and new varieties must be tentative.

*Design of experiments.*—Modern arrangements in randomized blocks or Latin squares, with or without split-plots, have been used in all the experiments; in some a single factor has been tested whilst others have included two or more factors using the standard factorial designs (Table 4). In all cases there has been adequate replication, and the standard errors per plot which were quoted were of the order of 10 per cent. of the mean yield.

*Types of experiments.*—Three types may be distinguished:

(*a*) Repeated trials: each successive crop in the series is treated, although not necessarily with the same amounts of fertilizer.
(*b*) Residual trials: untreated (or uniformly treated) ratoon crops follow differential treatments applied to the plant-canes, e.g. experiments with pen manure and by-products.
(*c*) Ratoon trials: test treatments are applied to the ratoons following a uniformly treated plant-cane crop.

Most of the experiments were of type (*a*) but some were a combination of (*a*) and (*b*), e.g. where pen manure and inorganic fertilizers were tested together. In some cases, where only ratoon results were available, the experiments were in fact of type (*a*). The results for ratoon trials (*c*)

TABLE 4. *Classification of the Crop Results according to the Type of Experiment and Nutrient involved*

| (i) | Nitrogen | | | | | | | | Phosphate | | | | | | | | Potash | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Plants* | | | *1st ratoons* | | | *2nd and other ratoons* | | *Plants* | | | *1st ratoons* | | | *2nd and other ratoons* | | *Plants* | | | *1st ratoons* | | | *2nd and other ratoons* | |
| *Type* \ *Levels* | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 | 2 | 3 | 4 |
| Repeated trials . . | 44 | 18 | 8 | 17 | 5 | 8 | 17 | 4 | 13 | 28 | 10 | 16 | 20 | 5 | 4 | 14 | 1 | 2 | 38 | 12 | | 26 | 7 | | 19 | 3 | |
| Residual trials . . | 5 | | | 7 | | | 2 | | | 3 | 2 | | 2 | 2 | | .. | | | | 1 | 3 | | 1 | 3 | | | 3 |
| Ratoon trials . . | .. | | | 8 | 1 | 2 | 6 | 3 | 11 | .. | | | 3 | 2 | 1 | 2 | 2 | 3 | .. | | | 4 | 1 | | 2 | 3 | |
| Total | 49 | 18 | 8 | 32 | 6 | 10 | 25 | 7 | 24 | 31 | 12 | 16 | 25 | 9 | 5 | 16 | 3 | 5 | 38 | 13 | 3 | 30 | 9 | 3 | 21 | 6 | 3 |

(ii) Single-factor experiments (including alternative forms of fertilizer) . . . 46

Factorial experiments:

| | |
|---|---|
| N, P, K . . . . | 14 |
| P, K . . . . | 16 |
| N, K . . . . | 10 |
| N, P . . . . | 21 |
| Miscellaneous . . . . | 16 |
| | 77 |
| Total . . . | 123 |

were found to be similar to the results for ratoon crops in repeated trials (*a*), and so these ratoon results, shown separately in Table 4, were in fact grouped together. Similarly, plant-cane responses in residual trials have been grouped with those of repeated trials. There were too few residual results to be analysed.

*Fertilizers.*—The fertilizers used and their nutrient equivalents were as follows:

| *Fertilizer* (*1 cwt.*) | *No. crops* | *Nutrient equivalent* |
|---|---|---|
| Sulphate of ammonia | 156 | 23·5 lb./acre N |
| Single superphosphate | 102 | 20 lb./acre $P_2O_5$ |
| Double superphosphate | 14 | 40 lb./acre $P_2O_5$ |
| Muriate of potash | 53 | 67·5 lb./acre $K_2O$ |
| Sulphate of potash | 65 | 56 lb./acre $K_2O$ |
| Nitrate of soda | 7 | Tested against equivalent amounts of sulphate of ammonia and superphosphate, as appropriate. |
| Ammonium nitrate | 3 | |
| Cyanamide | 1 | |
| Ammonium phosphate | 7 | |

The rates of dressings of nitrogen varied widely with a maximum application of 280 lb. per acre N. Although most of the phosphate dressings were in the range 20–60 lb. per acre $P_2O_5$, in a recent set of experiments considerably heavier dressings were used (maximum 180 lb. per acre $P_2O_5$). In three cases much larger dressings were used, 450 and 630 lb. per acre $P_2O_5$, but as these are outside the normal economic range these results were not included when evaluating the mean standard responses. With potash the amounts supplied were of the order of 100 lb. per acre $K_2O$. A few larger dressings (364 lb. per acre) were tried and also two experiments with excessively heavy dressings were encountered (maximum 804 lb. per acre $K_2O$). As with large phosphate dressings, the latter have been excluded.

*Standard responses.*—The trials differed considerably in the amounts of fertilizer applied. The responses were therefore standardized, using the same form of response curve as that employed by Crowther and Yates [4] and Carey and Robinson [2]. Details of this method are given in the Appendix. The standard dressings chosen were 50 lb. per acre for each of the plant nutrients: nitrogen (N), phosphate ($P_2O_5$), and potash ($K_2O$). It is also shown, in the Appendix, that the omission of the zero level of fertilizer reduces the accuracy of the estimated standard responses.

The standard errors of a single standard response given in the tables were estimated from the pooled variance of standard responses 'within classes'. Numbers of crops on which means are based are given in parentheses.

*Mean standard responses.*—Taking each nutrient in turn, the mean standard responses were obtained for each crop as a whole and also for each soil type.

All the experiments with phosphate and potash included the zero level, whereas in many of the nitrogen trials this level was omitted. Since additional dressings above comparatively high rates often produced substantial responses, e.g. in nine plant-cane trials the response

to nitrogen over the range 140–210 lb. per acre N was 1·4 t. per acre—the attempt was made to utilize the information contained in this class of experiment. It was, however, found that the standard plant-cane responses in these experiments were about six times as variable as those in experiments which included the zero level, whilst for the ratoon trials there was no significant difference in the variability of the standard responses in the two sets. This difference in variability of plant-cane responses was traced to one or more of the following causes: (*a*) The confounding of the straight response to nitrogen with the time of application as, for instance, where the application to the plant-canes was made in a single dose at the lower level, but in two doses in the first and second seasons at the higher level. (*b*) Very small incremental dressings. (*c*) The lower dressing being so high that the response to it (from zero) would be of the order 80 per cent. of the limiting response, i.e. relatively little additional response could be expected. The results in such cases were not used in forming Table 5.

TABLE 5. *Mean Standard Nitrogen Responses*

Standard dressing: 50 lb. per acre N ($k_N$ = 0·006 acres per lb.)

Tons per acre

| | *Plants* | | *1st ratoons* | | *2nd and other ratoons* | |
|---|---|---|---|---|---|---|
| *Variety* / *Soil* | *Old* | *New* | *Old* | *New* | *Old* | *New* |
| I | 4·2 (2) | 4·8 (1) | .. | .. | .. | .. |
| II | 5·2 (6) | 4·5 (3) | 2·1 (15) | 3·6 (4) | 4·6 (7) | 2·2 (1) |
| III | 3·8 (8) | 5·6 (8) | 5·7 (13) | 6·9 (3) | 5·4 (28) | 7·1 (4) |
| III′ | 3·0 (2) | 11·5 (3) | 5·9 (5) | 7·3 (1) | 6·6 (8) | 9·0 (1) |
| Mean | 4·2 (18) | 6·5 (15) | 4·1 (33) | 5·3 (8) | 5·5 (43) | 6·6 (6) |
| | ±3·10 (1) | | | | | |

*Nitrogen.*—From Table 5 sugar-cane seems to be most responsive to nitrogen on soil type III′. Soil types II and III, although giving similar yields of plant-cane and ratoons, differ in their responses to nitrogen, the more fertile type II giving rather lower responses. The first ratoons on type II seem to respond less rather than more than the plant-canes.

On the whole, the new varieties appear to respond rather more to nitrogen than the older ones, but in the absence of a combined manurial and varietal trial this point cannot be definitely settled. Even so, it appears likely that differences will depend on soil type. Such differences, however, may be expected in view of the higher mean yields of the newer varieties (Table 3).

The differences in repeated trials between the responses of plants and first ratoons and between first and second ratoons were obtained for 17 and 18 crop-series respectively (Table 6). Carey and Robinson

TABLE 6. *Mean Standard Nitrogen Responses for Crops in the Same Series in Repeated Trials*

Tons per acre

| *Soil* | *Plants* (*a*) | *1st ratoons* (*b*) | *Difference* (*a*)−(*b*) | *No. expts.* | *1st ratoons* (*b*) | *2nd ratoons* (*c*) | *Difference* (*b*)−(*c*) | *No. expts.* |
|---|---|---|---|---|---|---|---|---|
| II | 4·7 | 2·8 | +1·9 | (7) | 3·9 | 3·2 | +0·7 | (5) |
| III | 4·5 | 6·6 | −2·1 | (8) | 6·2 | 6·0 | +0·2 | (10) |
| III′ | 5·9 | 8·6 | −2·7 | (2) | 8·0 | 7·5 | +0·5 | (3) |
| Mean | 4·8 | 5·3 | −0·5 | (17) | 5·9 | 5·5 | +0·4 | (18) |
| | | | ±4·15 | (1) | | | ±3·49 | (1) |

[2] give mean plant-cane and first ratoon responses in repeated trials of 2·1 and 4·4 t. per acre respectively for all territories. Although the responses given in Table 6 are larger, the differences are similar except on soil type II. The anomalous result for this soil type is due in part to reduced responses of four of the ratoon crops, owing to froghopper damage.

*Kind of nitrogen.*—Nitrate of soda was tested against sulphate of ammonia in five experiments (plant-cane crops only, excluding 'standovers') giving respectively standard responses of 2·2 and 1·8 t. per acre. Ammonium nitrate was compared with sulphate of ammonia in one experiment of three crops duration in which the mean standard responses for the series were respectively 7·1 and 7·9 t. per acre.

TABLE 7. *Mean Standard Phosphate Responses*

Standard dressing 50 lb. per acre $P_2O_5$ ($k_P$ = 0·010 acres per lb.)

Tons per acre

| | *Plants* | | *1st ratoons* | | *2nd and other ratoons* | | *Mean* | |
|---|---|---|---|---|---|---|---|---|
| *Variety* / *Soil* | *Old* | *New* | *Old* | *New* | *Old* | *New* | *Old* | *New* |
| I | 0·0 (4) | −1·7 (3) | 1·9 (2) | .. | .. | .. | 0·6 (6) | −1·7 (3) |
| II | 0·6 (14) | 3·1 (4) | 1·0 (13) | 1·4 (3) | 1·3 (4) | 1·3 (5) | 0·8 (31) | 1·9 (12) |
| III | 1·8 (17) | 4·8 (5) | 1·7 (13) | 4·1 (1) | 1·9 (11) | 4·5 (1) | 1·8 (41) | 4·7 (7) |
| III′ | 1·9 (7) | 2·6 (3) | 1·0 (4) | .. | 0·8 (3) | .. | 1·4 (14) | 2·6 (3) |
| Mean | 1·2 (42) | 2·6 (15) | 1·3 (32) | 2·1 (4) | 1·6 (18) | 1·8 (6) | 1·3 (92) | 2·3 (25) |
| | ±1·84 (1) | | | | | | | |

*Phosphate.*—Table 7 shows that there is no response on soils of type I, and on the others the standard responses are mostly fairly small (0·7–2·0 t. per acre). As with nitrogen, the soil type III gives a larger response than type II; on III′ the response is intermediate between these two.

The newer varieties again appear to respond better than the old ones, especially on soil type III. These varieties have been tested over a

limited period and not in the same experiment as any of the others, so that at present the results of this comparison must be accepted with some reserve. Greater responses are, however, to be expected from crops that give generally higher yields (see Table 3).

For those experiments where the available phosphate in the top-soil was given, the responses have been grouped according to the available phosphate being above or below 30 p.p.m. $P_2O_5$ (Truog) and according to the crop. The results are given in Table 8.

TABLE 8. *Relation between Standard Phosphate Response and Available Phosphate in the Soil (p.p.m. $P_2O_5$)*

Tons per acre

| *Available* $P_2O_5$ | *Plants* | *1st ratoons* | *2nd ratoons* |
|---|---|---|---|
| Less than 30 p.p.m. . . | 2·0 (9) | 2·0 (5) | 1·9 (4) |
| Over 30 p.p.m. . . . | 0·4 (13) | 1·3 (14) | −0·4 (4) |
| | ±1·22 (1) | | |

There thus appears to be quite a close association between the response obtained and the amount of the available phosphate in the soil as determined by soil analysis.

TABLE 9. *Mean Standard Phosphate Responses for Crops in the Same Series in Repeated Trials, in relation to Available Phosphate in the Soil*

Tons per acre

| *Available* $P_2O_5$ | *Plants* (*a*) | *1st ratoons* (*b*) | *Difference* (*a*)−(*b*) | *1st ratoons* (*b*) | *2nd ratoons* (*c*) | *Difference* (*b*)−(*c*) |
|---|---|---|---|---|---|---|
| Less than 30 p.p.m. . . | +3·5 | +2·0 | +1·5 (5) | +1·9 | +2·4 | −0·5 (3) |
| Over 30 p.p.m. . . | +0·4 | +1·0 | −0·6 (12) | +0·6 | −0·4 | +1·0 (4) |
| | | | ±1·99 (1) | | | ±1·13 (1) |

In Table 9 the differences between the responses of successive crops in the same series are examined.

*Kind of phosphate.*—In six experiments involving eight crops, ammonium phosphate was tested against superphosphate in the presence of basal nitrogen. On only one of the eight crops did ammonium phosphate give a better response than superphosphate. The mean responses over all the crops were 0·4 and 1·0 t. per acre respectively.

*Potash.*—The responses to potash in relation to the soils (Table 10) are generally small except on soil type I, but as with phosphate the magnitude of the response seems to depend on the amount of available potash as shown by soil analysis of the experimental site rather than on the above soil classification; in fact with potash it is rather more marked (see Table 11). The borderline of potash deficiency is about 80 p.p.m. of exchangeable potash as $K_2O$ and so the standard responses have been grouped

accordingly (Table 11), wherever the data on available potash were given. As expected, on the low potash areas the crops respond more to potash fertilizer, but whilst this difference is maintained in the ratoon crops it is not so pronounced. Table 12 shows that there is little difference in response between plants and ratoons.

TABLE 10. *Mean Standard Potash Responses*

Standard dressing 50 lb. per acre ($k_K$=0·010 acres per lb.)

Tons per acre

| *Soil* | *Plants* | *1st ratoons* | *2nd and other ratoons* | *Mean* |
|---|---|---|---|---|
| I | 4·3 (6) | 3·9 (1) | .. | 4·2 (7) |
| II | 1·9 (25) | 1·8 (16) | 1·7 (8) | 1·8 (49) |
| III | 1·9 (15) | 2·1 (14) | 1·7 (12) | 1·9 (41) |
| III′ | 0·6 (7) | 1·4 (5) | 0·6 (4) | 0·8 (16) |
| Mean | 2·0 (53) | 1·9 (36) | 1·5 (24) | 1·9 (113) |
| | ±1·67 (1) | | | |

TABLE 11. *Relation between Standard Potash Responses and Available Potash in the Soil (p.p.m.* $K_2O$)

Tons per acre

| *Available* $K_2O$ | *Plants* | *1st ratoons* | *2nd ratoons* |
|---|---|---|---|
| Less than 80 p.p.m. . . | 3·5 (22) | 2·6 (19) | 2·5 (10) |
| Over 80 p.p.m. . . . | 0·8 (12) | 1·1 (10) | 0·8 (5) |
| | ±1·42 (1) | | |

TABLE 12. *Mean Standard Potash Responses for Crops in the Same Series in Repeated Trials in relation to Available Potash in the Soil*

Tons per acre

| *Available* $K_2O$ | *Plants* (*a*) | *1st ratoons* (*b*) | *Difference* (*a*)−(*b*) | *1st ratoons* (*b*) | *2nd ratoons* (*c*) | *Difference* (*b*)−(*c*) |
|---|---|---|---|---|---|---|
| Less than 80 p.p.m. . . | 3·5 | 2·8 | +0·7 (17) | 2·4 | 3·0 | −0·6 (8) |
| Over 80 p.p.m. . . | 0·8 | 1·1 | −0·3 (8) | 1·4 | 0·9 | +0·5 (4) |
| | | | ±1·43 (1) | | | ±0·80 (1) |

*Pen manure.*—The pen manure was applied in every case to the plant-canes so that ratoon responses reflected the residual effect of the initial application. In the experiments it was either applied alone or in a factorial arrangement with inorganic fertilizers, which were applied to each crop. The mean responses to the standard dressing of 20 t. per acre of pen manure are given in Table 13. There appears to be little variation with soil type. In the presence of inorganic fertilizers, the responses are lower than to pen manure alone. The second section of the table gives comparisons

within the same experiments and indicates the differences due to the presence of nitrogen, potash, and phosphate. The two latter comparisons were obtained from a large, long-term experiment on a soil deficient in potash but not in available phosphate. Two samples of pen manure showed that 20 tons supplied approximately 180 lb. N, 80 lb. $P_2O_5$, and 260 lb. $K_2O$. The potash-content of the pen manure together with the deficiency in this nutrient on the experimental site probably accounts for the large difference in response in the presence and absence of inorganic potash. The residual response of the first ratoons is about one-third the direct response, whilst the second ratoons still show some effect of the original application. The effect may persist over an even longer period, as far as third ratoons or even to a second plant-cane crop planted after three previous crops.

TABLE 13. *Mean Standard Responses to Pen Manure*

Standard dressing 20 t. per acre ($k_M$ = 0·03 acres per ton)

Tons per acre

| | *Soil* | *Plants* | *1st ratoons* | *2nd ratoons* |
|---|---|---|---|---|
| Pen manure alone . . . | II | 7·4 (5) | 2·3 (4) | 2·9 (1) |
| | III | 5·9 (3) | 0·2 (1) | .. |
| | III′ | 5·9 (1) | 4·5 (1) | 2·2 (1) |
| | Mean | 6·7 (9) | 2·3 (6) | 2·6 (2) |
| Pen manure *plus* fertilizers as indicated. (Comparisons in the same experiments) . . . . | .. | 4·6 (3) | −0·6 (2) | .. |
| | N | 4·2 | +0·8 | .. |
| | NP | 7·6 (5) | 3·3 (6) | 2·1 (2) |
| | NPK | 4·8 | 1·9 | 0·5 |
| | NK | 4·8 (5) | 2·4 (6) | 0·8 (2) |
| | NPK | 4·4 | 1·5 | 0·4 |

*Effect of fertilizers on sugar percentage.*—Table 14 shows the mean sugar percentage at different levels of fertilizer in various series of crops, the numbers of which are appended. (The average sucrose-content of the cane was about 2% greater.)

Nitrogen and phosphate both reduce the sugar percentage; potash generally is beneficial. The data showed any interaction effects of the fertilizers on sugar percentage to be very small. From the experiments with alternative forms of fertilizer, there was little variation of sugar percentage with the form used.

*By-products.*—In this section the results are assembled of six experiments with filter-press mud (in the presence of basal nitrogen) and three with molasses. The value of the filter-press mud as a fertilizer lies mainly in its phosphate content (3 per cent. $P_2O_5$), most of which is readily available; the main nutrient supplied by molasses is potash (3 per cent. $K_2O$). Table 15 gives the direct responses of plant-canes and residual responses of the first and second ratoon crops, standardized on the basis of their respective phosphate and potash contents.

TABLE 14. *Relation between Average Sugar Percentage and Level of Fertilizer*

| *Nitrogen* | | | *Phosphate* | | | *Potash* | | |
|---|---|---|---|---|---|---|---|---|
| *No. crops* | *Amount (lb. per acre N)* | *% sugar* | *No. crops* | *Amount (lb. per acre $P_2O_5$)* | *% sugar* | *No. crops* | *Amount (lb. per acre $K_2O$)* | *% sugar* |
| 10 | 0 | 11·01 | 12 | 0 | 11·40 | 5 | 0 | 11·34 |
| | 35 | 11·06 | | 20 | 11·19 | | 67 | 11·49 |
| | 70 | 11·19 | 9 | 0 | 11·14 | | 134 | 11·63 |
| | 105 | 10·65 | | 30 | 11·19 | 15 | 0 | 11·27 |
| 4 | 0 | 12·66 | 9 | 0 | 10·95 | | 84 | 11·38 |
| | 88 | 11·53 | | 40 | 10·76 | 4 | 0 | 11·43 |
| | 176 | 11·36 | 10* | 0 | 11·66 | | 101 | 11·82 |
| | 264 | 11·01 | | 60 | 11·60 | 33 | 0 | 10·87 |
| 16* | 70 | 11·74 | | 120 | 11·45 | | 112 | 11·04 |
| | 140 | 11·42 | | 180 | 11·52 | 5 | 0 | 9·76 |
| | 210 | 11·48 | 4 | 0 | 11·68 | | 168 | 9·78 |
| 18 | 70 | 10·95 | | 180 | 11·55 | 4 | 0 | 11·33 |
| | 140 | 10·75 | | | | | 364 | 11·90 |

* New varieties.

Treatment with an average dressing of 10 t. per acre of filter-press mud changed the sugar percentage from 10·58 to 10·72; the corresponding change due to an application of 5 t. per acre molasses in one experiment was from 10·71 to 10·42 (cf. Table 14).

TABLE 15. *Standard Responses to Filter-press Mud and to Molasses*

Tons per acre

| | *Plants* | *1st ratoons* | *2nd ratoons* |
|---|---|---|---|
| Filter-press mud (3% $P_2O_5$) . | 0·8 (6) | 1·6 (2) | 1·0 (1) |
| Molasses (3% $K_2O$) . . | 3·4 (3) | 1·4 (2) | 0·5 (1) |

*Summary.*—Using experimental results obtained within the past 20 years in Trinidad, mean standard responses of plant-canes, first ratoons and second ratoons to nitrogen, phosphate, potash, pen manure, and by-products have been obtained. Responses to nitrogen have been associated with the moisture characteristics of the soils, whilst those of phosphate and potash depend rather on the quantities of these nutrients available in the soils. In this series of experiments there were no great differences in response of plant-canes and ratoons. The newer varieties showed rather greater responses than the old. Nitrogen and phosphate somewhat reduced the sugar percentage, potash increased it.

*Acknowledgement.*—I wish to thank Dr. F. Yates for his guidance and criticism throughout the preparation of this paper.

## REFERENCES

1. P. E. TURNER *et al.*, Field Experiments on Sugar Cane in Trinidad. Annual Reports of the Sugar Cane Investigation Committee, 1936–50.
2. T. M. CAREY and P. ROBINSON, The Manuring of Sugar Cane: Empire J. Expt. Agric. (In the press.)
3. C. F. CHARTER, A Tentative Grouping of Sugar Cane Soils on the Basis of their Moisture Relationships: Annual Reports of Sugar Cane Investigation Committee, 1941, 1942.
4. E. M. CROWTHER and F. YATES, Fertilizer Policy in Wartime, Empire J. Expt. Agric., 1941, **9**, 77.
5. W. L. STEVENS, Asymptotic Regression. Biometrics 1951, **7**, 247.

(Received November 1, 1952)

## APPENDIX

In computing the standard responses the Mitscherlich form of response curve has been used. The relation between the yield per acre ($y$) and a dressing $x$ lb. per acre is given by

$$y = y_0 + d(1 - 10^{-kx}), \tag{1}$$

where $y_0$ is the yield with no fertilizer, $d$ is the limiting response and $k$ is a positive constant which determines the curvature of the response curve.

If a dressing $s$ lb. per acre is taken as standard the *relative* response curve has the form

$$R(x) = \frac{1 - 10^{-kx}}{1 - 10^{-ks}}. \tag{2}$$

The values of the constant $k$ (in acres per lb.) which were adopted, were those used by Carey and Robinson [2], viz.

$$k_N = 0{\cdot}006 \qquad k_P = 0{\cdot}010 \qquad k_K = 0{\cdot}010.$$

For pen manure the value $k_M = 0{\cdot}03$ acres per t. was used.

The estimates of $k$, which were obtained from experiments with three or more levels of fertilizer, confirmed the general reliability of these values, although there remains considerable scope for improvement in the determination of such values on the lines given by Stevens [5].

On accepting the above constant values for $k_N$, $k_P$, and $k_K$, the yield for a dressing $x$ may be written

$$y = y_0 + dx',$$

where $x' = (1 - 10^{-kx})$. Thus for sets of values $(x, y)$ or $(x', y)$ this curve may be fitted by the method of least squares, i.e. linear regression of $y$ on $x'$. In this way, the parameters $y_0$ and $d$ may be estimated, whence the standard response is given by

$$d(1 - 10^{-ks}). \tag{3}$$

It is not necessary to estimate $d$ explicitly, for by using (2) the standard response may be obtained in the form

$$\frac{nS(Ry) - S(R)S(y)}{nS(R^2) - [S(R)]^2} = S(\lambda y),$$

where $n$ is the number of levels of fertilizer employed, and $\lambda$ are weights applied to the original yields at the different levels. For computational purposes the values of $\lambda$, given by

$$\lambda = \frac{nR - S(R)}{nS(R^2) - [S(R)]^2},$$

are first calculated for the different series of experiments.

For experiments with two levels only, this procedure reduces to the division of the actual by the relative response.

If $\sigma$ is the standard error of the average yield at each level of a fertilizer, then the variance of the estimated standard response is $S(\lambda^2)\sigma^2$. The effects on this variance of changes in the number of levels, incremental dressings and presence or absence of the zero level are shown in Table 16.

TABLE 16. *Variances of Estimated Standard Responses in Terms of the Variance of the Mean Yields*

Standard dressing $s = 50$ lb. per acre

| *Lowest level* (*lb. per acre*) | $k$ (*acres per lb.*) | *Incremental dressing* (*lb. per acre*) | *Variance of standard response* | |
|---|---|---|---|---|
| | | | *3 levels* | *4 levels* |
| 0 | 0·010 | 20 | $2{\cdot}54\sigma^2$ | $1{\cdot}46\sigma^2$ |
| | | 30 | $1{\cdot}61\sigma^2$ | $1{\cdot}04\sigma^2$ |
| | | 40 | $1{\cdot}24\sigma^2$ | $0{\cdot}88\sigma^2$ |
| | | 60 | $0{\cdot}95\sigma^2$ | $0{\cdot}75\sigma^2$ |
| 0 | 0·006 | 47 | | $0{\cdot}58\sigma^2$ |
| 47 | | 47 | | $2{\cdot}13\sigma^2$ |
| 0 | | 70 | | $0{\cdot}46\sigma^2$ |
| 70 | | 70 | | $3{\cdot}16\sigma^2$ |

Thus, for a constant value of $\sigma^2$, the information on the standard response is increased when the incremental dressing or the number of levels is increased or both. The information is also considerably greater when the zero level is present. For instance, with incremental dressings of 70 lb. per acre and four levels of fertilizer the information will be seven times greater when the zero level is included than when the first level is 70 lb. per acre.

# PUBERTY IN FEMALE FARM ANIMALS

E. S. E. HAFEZ

(*Faculty of Agriculture, Cairo University, Egypt*)

PUBERTY in the female is associated with pronounced physiological, anatomical, physical, and psychological changes. It is a gradual phenomenon and complete sexuality is not acquired all at once. To arouse the reproductive faculty, external stimuli are required, the nature of which varies widely with different species. The onset of puberty and the functioning of the ovary is determined by the changes occurring in the anterior pituitary gland. Before puberty, the level of gonadotrophic hormones of the pituitary is insufficient to ripen the follicles. Also, the ovary has not developed to a stage to respond to gonadotrophic stimulation. Circumstances affecting the responsiveness of the ovary to gonadotrophic hormones have been discussed by Burrows [1]. After puberty one or more follicles will ripen at every oestrus in response to a corresponding periodical increase in the supply of the follicle-stimulating hormone (F.S.H.) of the pituitary. The ovaries increase in size with the increase of age even after puberty [2]. The most pronounced anatomical change associated with puberty is the alteration in the general proportions of the body. There are connexions between body-size and age of puberty, probably due to the interactions between the growth and gonadotrophic hormones [3]. Physical and psychological changes that appear at puberty in the woman are less pronounced in farm animals.

Different species vary in their pattern of reproduction. Domestication has accelerated puberty, a fact of great economic and academic interest. Genetic and environmental factors play a role in determining the age and live-weight at puberty. In sheep, the average age and live-weight at first oestrus are 240 days and 92 lb. for the Suffolk breed and 238 days and 66 lb. for the Blackface Mountain, these differences being significant [4]. The formation of follicles in the ovaries begins at the age of 5 months in the Whitefaced mutton sheep and at 7 to 18 months in Heidschnuke sheep [2]. In cattle, breed differences in the age of first oestrus have been shown by Hammond [5] and Schmaltz [6]. The effect of sire on the age of puberty has been suggested by Warnick *et al.* [7]. Pullets of heavy breeds lay their first egg when they are about one month older than those of light breeds, unless the flock has been selected for early egg-laying [8]. In swine, line- and year-differences in both age and live-weight at puberty are highly significant whilst the line × year interaction is significant for the weight at puberty but not for the age at puberty [7].

The age of puberty is controlled by the season of birth as reported in sheep [9, 10], in rabbits [11], in hens [12, 13], in pigeons [14], in pigs [7], and is probably due to the changes in the daylight environment. Also the stage of sexual development is correlated with the season of birth [15].

[Empire Journ. of Exper. Agric., Vol. 21, No. 83, 1953.]

The age and live-weight of the first egg laid is determined by nutrition, as demonstrated in poultry, and is attributed to the mineral content of the ration [16] or to the quantity and quality of protein [17].

This study is an attempt to investigate the phenomenon of puberty in the female of three species of farm animals with different patterns of reproduction, namely sheep, rabbits, and fowls; special reference is given to its relation to animal production and growth.

## *Material and Methods*

Two breed groups of fat-tailed ewe lambs were available; 16 of Rahmani breed (Nos. 1 to 16) and 16 of Ossimi breed (Nos. 17 to 32). They were born between October and December 1950 and were weaned at the age of 4 months. Each group was joined with two fertile rams of 2 to 3 years' old. The rams were ochred daily on the brisket, and oestrus observations were carried out daily. All heat periods were recorded until pregnancy was established. Pregnancy was diagnosed by vaginal-smear technique [4]. Lambing took place during the spring months.

Twelve Baladi doe rabbits (native breed) of albino type were available at the age of 2 months. They were born during November and December 1950 of different litters. They were tried individually with fertile bucks (14 months' old) every week. They were mated weekly until pregnancy took place. Pregnancy was diagnosed by abdominal palpation ten days from mating.

Fifty Fawomi pullets were selected at random at the age of 3 months. The dates of hatching were October and November 1950. They were joined with ten fertile cocks 15 months' old. Trap nests were available to record the sequence of egg-laying of each individual. The first ten eggs laid by the chicks were incubated in 'Hearson' incubators to test the hatchability of the eggs. Eggs were examined with an electric bulb on the seventh day of incubation to determine fertilization.

The four groups of experimental animals were derived from the flocks of the Animal Research Farm of Cairo University. They had been closely inbred for more than ten years. The animals were fed *ad lib.* with concentrates and green fodder. They were weighed monthly. This experiment lasted a year, starting from September 1951. The event which determined puberty in the three species was regarded as the occurrence of first oestrus in ewe lambs, the first conception in does, and the first egg laid in chicks.

## *Results*

(*a*) *Ewe lambs.*—Rahmani ewe lambs showed their first oestrus from October 10 to January 12 with an average date of December 10. Ossimi ewe lambs experienced their first oestrus from October 6 to December 29 with an average of October 28, being six weeks earlier than the Rahmani breed. Two Rahmani ewe lambs and one Ossimi did not show any oestrus and were culled as sterile; they were not included in the average. The age at first oestrus in the Rahmani group ranged from 378 to 427 days with an average of 394·4 days. In the Ossimi it ranged from 333 to 399 days with an average of 358·5 days, being 36 days younger than

the Rahmani. The live-weight at first oestrus in the Rahmani breed ranged from 27 to 38 kg. with an average of 32·2 kg. In the Ossimi it ranged from 26 to 37 kg. with an average of 30·9 kg. (Table 1). There was no significant difference in the live-weight at first oestrus in the two breeds. The live-weight and age at first oestrus were, however, correlated

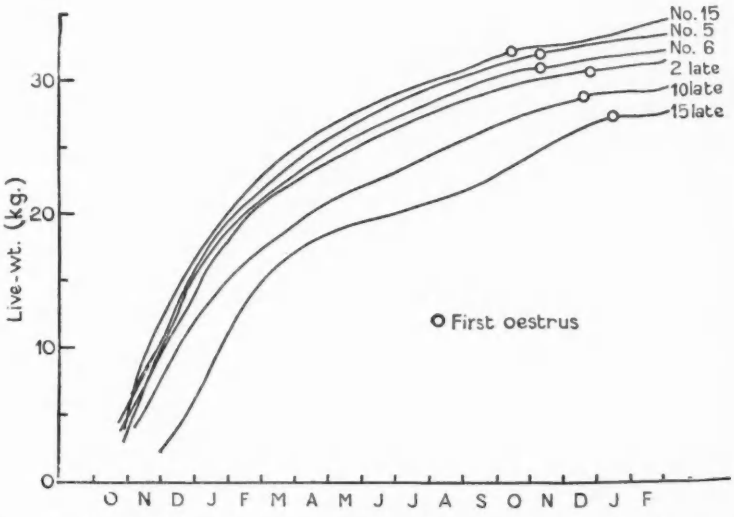



FIG. 1. Individual differences in the occurrence of first oestrus in relation to growth-curves of Rahmani ewe lambs. (Fast-growing animals experience their first oestrus earlier than slow-growing ones.)

with the growth-rates of the individuals as shown in Figure 1. Ewe lambs with high growth-rate showed their first oestrus at a younger age and a higher live-weight.

TABLE 1. *Age and Live-weight at Puberty*

| *Species* | *Breed* | *No. of females* | *Criterion of puberty* | *Average age (days)* | *Average live-weight* |
|---|---|---|---|---|---|
| Ewe (fat-tailed) | Rahmani | 16 | first oestrus | 394·4 | 32·2 kg. |
| ,, ( ,, ,, ) | Ossimi | 16 | ,, ,, | 358·5 | 30·9 ,, |
| Doe rabbit . | Baladi | 12 | first conception | 136·7 | 1701·7 gm. |
| Pullet . . | Fawomi | 50 | egg laid | 143·6 | 976·7 ,, |

Figure 2, however, shows breed differences in the age at first oestrus and in the nature of puberal conception in ewe lambs. Conception in the Rahmani ewe lambs took place after one to two services with an average of 1·1 services. In the Ossimi it ranged from one to six services per conception with an average of 2·2. In some cases silent heats

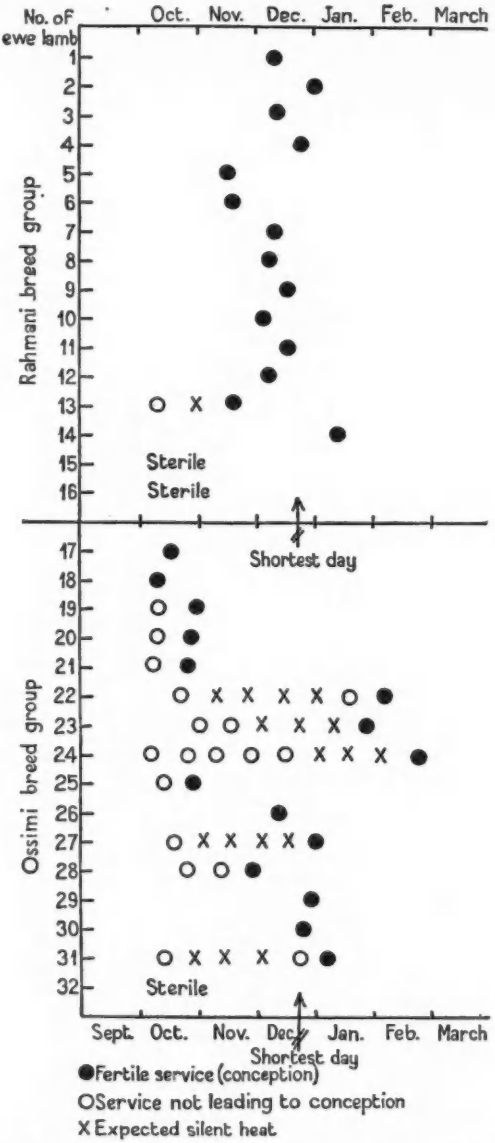



FIG. 2. Breed differences in date and age at first oestrus and in the nature of puberal conception. (Ewe lambs of Rahmani and Ossimi breeds, born in October and November, joined with ochred fertile rams.)

(ovulation without oestrus) took place between the occurrence of first oestrus and the date of conception. This was more frequent in the Ossimi breed group. In the Rahmani group silent heat occurred once (No. 13). In the Ossimo breed silent heat occurred in five ewe lambs out of sixteen (31 per cent.); the range was from one to four successive silent heats.

In the Rahmani group 1 animal aborted, 2 animals delivered still-births, and 11 gave singles. In the Ossimi group, 2 animals aborted, 1 delivered still-born, 11 delivered singles, and 1 gave twins. In the normal breeding flock (breeding adults) kept at the Research Farm, the twinning percentage for this year was 27 for the Rahmani and 44 for the Ossimi. In the experimental animals, lambing took place during the spring months and the gestation period was similar to that of the breeding adults. In the breeding of ewe lambs, the birth-weight of the young ranged from 2·65 to 3·95 kg. with an average of 3·14 kg. for the Rahmani and from 2·35 to 3·75 kg. with an average of 2·96 kg. in the Ossimi. The sex ratio in both breed groups was 1 : 1·1. All the mothers were lactating, the udder development being normal. The young born survived during the suckling period but mortality occurred at weaning time, which synchronized with the summer months (severe hot climatic conditions).

(*b*) *Does.*—The does were first mated from March 14 to April 11 with an average date of March 25. The date of conception ranged from February 28 to May 5 with an average of April 11. The age at first conception ranged from 117 to 168 days with an average of 136·7 days, whilst the corresponding live-weight ranged from 1,550 to 1,840 gm. with an average of 1,701·7 gm. (see Table 1). The number of matings (at weekly intervals) required for conception ranged from 2 to 6 with an average of 2·7. All does delivered young except in case of abortion. The gestation period was as long as that in breeding adults; 7 per cent. of the young delivered were still-births and were not included in the averages. Litter-size ranged from 3 to 8 with an average of 5·2. The average birth-weight was 27·1 gm.; it varied according to litter-size. The sex ratio was 1·1 : 1. All the mothers were lactating. During the nursing period, the mortality rate in the young was 17 per cent.

(*c*) *Pullets.*—The pullets laid their first egg from March 20 to May 21 with an average of April 21. The age at first egg laid ranged from 114 to 181 days with an average of 143·6 days and the corresponding live-weight ranged from 620 to 1,346 gm. with an average of 976·7 gm. (see Table 1).

The weight of the first egg laid ranged from 22 to 37 gm. with an average of 26·5 gm. The maximum weight of eggs laid during the first year of egg production ranged from 40 to 52 gm. with an average of 44·1 gm. The average weight of the first egg laid expressed as a percentage of the average maximum egg-weight was 62. In some cases the first egg laid was fertilizable and even hatchable when incubated. The chicks resulting from such incubated eggs were subjected to severe hot climatic conditions and the mortality rate was as high as 82 per cent.

(*d*) *General.*—The average weight at puberty expressed as a percentage of the average birth-weight varied in the three species (Table 2). Figure

3 shows the species differences in the age and live-weight at puberty in relation to post-natal growth-rate. The average live-weight at puberty when expressed as a percentage of the adult weight of the species was 69 in sheep, 85 in rabbits, and 73 in hens.

TABLE 2. *Weight at Puberty expressed as a Percentage of Birth-weight and Adult-weight*

| *Species and breed* | *Average live-wt. at puberty* | *Puberty wt. as % of birth-wt.* | *Puberty wt. as % of adult-wt.* |
|---|---|---|---|
| Fat-tailed ewe lambs . | 31·6 kg. | 894 | 69 |
| Baladi rabbit does . | 1702 gm. | 3621 | 85 |
| Fawomi pullets . | 977 ,, | 3033 | 73 |

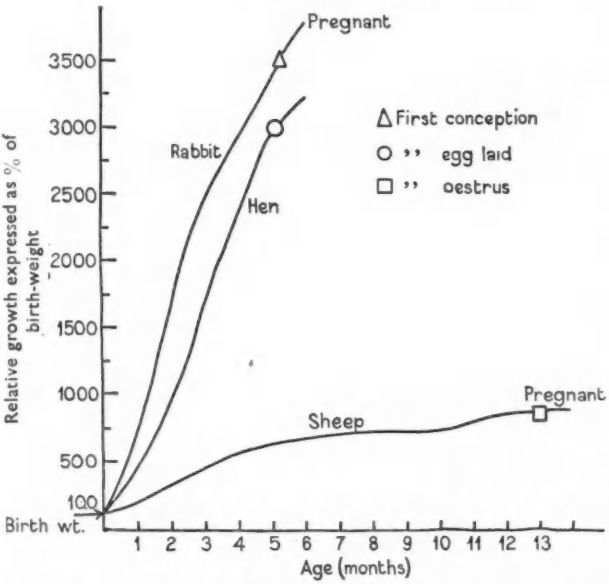



FIG. 3. Species differences in the age and live-weight at puberty in relation to post-natal growth. (Fat-tailed ewe lambs, Baladi rabbit does, and Fawomi pullets.)

## *Discussion*

In sheep, first oestrus occurs during the shortest days of the year (December), as found by Hammond Jr. [9] and Hafez [4], who worked in the northern hemisphere. The same phenomenon applies to the southern hemisphere, where ewe lambs experience their first heat in June (shortest days) in New Zealand [18] and from February to April in Australia [19]. It is, however, possible that the fat-tailed ewe lambs at this latitude (30° N.) show their first oestrus irrespective of the day-

light environment owing to the little variation in the day-length. This could only be proved by determining the age at first oestrus in two groups of ewe lambs, one born in the longest days and the other during the shortest days. There are breed differences in the age at first oestrus; this denotes a genetic background for differences in age of puberty.

Conception in the Rahmani group takes place after an average of 1·1 services. This shows that the first oestrus is accompanied by ovulation. It is suggested here that the oestrus first observed in ewe lambs is preceded by one or more silent heats (ovulation without oestrus), as the ewe lambs show in the field some sexual desire about 16 days before the first heat. This could be confirmed by post-mortem examination of the ovaries just before the first oestrus. In the Ossimi group the occurrence of silent heats is more frequent and the nature of conception at puberty is different from that of the Rahmani breed (see Fig. 2). This denotes that genetic factors are involved in the expression of silent heats and in conception. In some cases three to four successive silent heats are recorded (Nos. 22, 23, 24, 31 Ossimi). It is possible that they are not actual heats, and the ovaries did not show any periodic activity (every 16 days) due to implantation followed by early foetal mortality.

There is practically no twinning in the breeding of ewe lambs. This is probably due to a few ova being shed from the ovary. The number of ova shed might be the same in ewe lambs and adults, but the number of ova capable of fertilization might be less in the younger age-groups. It is suggested that in some cases, especially in the Ossimi breed, the endometrial walls are not always mature for implantation in ewe lambs, so that puberal conception does not take place at the occurrence of first oestrus.

The average birth-weight of the young produced from ewe lambs is 3·14 kg. for the Rahmani and 2·96 kg. for the Ossimi. The corresponding figures for birth-weights of young delivered from adults is 3·67 and 3·55 kg. as reported by Badreldin [20], who worked on the same flock. When breeding rabbits at puberty the average litter-size is 2·7 and the average birth-weight is 27·1 gm. The corresponding figures for adult rabbits is 6·49 and 45·7 gm. [21]. Squiers *et al.* [22] reported in gilts at puberty an increase of 0·5 pigs for each ten days increase in the age at breeding, due in part to an association between ovulation-rate and age. Also Robertson *et al.* [23] suggested that litter-size increases with the order number of the heat period at which gilts conceive up to the third period when it tends to level off.

In poultry, the first egg laid synchronizes with long days. It is not known how far sexual maturity in the hen is controlled by daylight environment in tropical and sub-tropical countries. It is possible that under hot climatic conditions, atmospheric temperature plays a part in the onset of sexual maturity in the hen. Individual variation is more in the live-weight at first egg than in the age at first egg. Although the first eggs laid are inferior in weight, they may be fertilizable and even hatchable. Many investigators [24, 25, and others] have shown that the age of first egg laid by pullets has considerable negative correlation with egg-production. Also, the time of the first egg has a curvilinear association with the subsequent winter egg-production [26].

In ewe lambs first oestrus is experienced earlier in faster-growing ones than in others. It should be possible to predict, within limits, the age at puberty from body-weight at given ages. It is of great interest to find out the correlations between body-weight at different ages and live-weight at puberty. In rats, females from small litters reach puberty earlier than animals from large litters, chiefly because of differences in growth-rate [27]. The individual differences in the age and live-weight at puberty may be correlated with subsequent reproductive and productive capacity of the animal. This provides a basis for prediction. Selection for early puberty on the basis of body-weight may be more effective at one particular age and also may be more effective in certain breeds than in others.

It may be concluded that the anterior pituitary gland is a channel through which hereditary (species, breed and individual) and environmental (seasonal and nutrition) factors influence the age and live-weight at puberty. In the field of animal production it should be possible to accelerate the age of puberty in farm animals by the administration of sex and gonadotrophic hormones, by applying artificial illumination or increasing the plane of nutrition. Since puberty is an inherited character, breeding experiments could be carried out in order to build up strains of animals with early puberty.

In the male puberty takes place in several steps: the onset of spermatogenic activity (as revealed by histological examination of the testes), the start of ejaculation (ejaculates containing spermatozoa), the desire to mate, and the emission of fertilizable spermatozoa. The sequence and the time-interval of this chain of events are not known in the male of farm animals. The age and live-weight at puberty in the male in relation to that of the female of the same species is of great interest. Environmental factors may have different effects on the phenomena of puberty in both sexes of the same species.

## *Summary*

1. There are species, breed, and individual differences in the age and live-weight at puberty in the female. Environmental factors also determine this phenomenon.

2. The average age at puberty was 394·4 days (first oestrus) in Rahmani and 358·5 days in Ossimi ewe lambs, 136·7 days (first conception) in Baladi rabbit does, and 143·6 days (first egg laid) in Fawomi pullets. The corresponding average live-weights were 32·2, 30·9, 1·7, and 1·0 kg. respectively.

3. An association between growth and puberty was found. The weight at puberty when expressed as a percentage of the birth-weight was 894 in sheep, 3,621 in rabbits and 3,033 in hens. Weight at puberty when expressed as a percentage of adult weight was 69, 85, and 73 respectively.

4. Phenomena related to puberty, such as conception at the time of puberty, have a genetic background.

5. Some practical applications of knowledge concerning puberty are discussed.

*Acknowledgements.*—This work was carried out in the Department of Animal Breeding, Faculty of Agriculture, Cairo University, Egypt. Thanks are due to Prof. A. L. Badreldin for providing facilities and criticism.

## REFERENCES

1. H. Burrows, Biological Actions of Sex Hormones, Cambridge, 1949, p. 83.
2. G. Voss, Neue Ergebnisse und Probleme der Zoologie, Leipzig, 1950, p. 1028.
3. J. Hammond and F. H. A. Marshall, Marshall's Physiology of Reproduction, edited by F. H. A. Marshall, London, 1952, p. 822.
4. E. S. E. Hafez, Studies on the Breeding Season and Reproduction of the Ewe. J. Agric. Sci., 1952, **42**, 189, 232.
5. J. Hammond, Reproduction of the Cow, Cambridge, 1927, p. 7.
6. G. Schmaltz, Das Geschlechtsleben der Haussäugetiere. Berlin, 1921, p. 18.
7. A. C. Warnick, E. L. Wiggins, L. E. Casida, R. H. Grummer, A. B. Chapman, Puberty Phenomena in Inbred Gilts. J. Anim. Sci., 1951, **10**, 481.
8. A. L. Romanoff, A. J. Romanoff, The Avian Egg, New York, 1949, p. 22.
9. J. Hammond, Jr., On the Breeding Season in Sheep. J. Agric. Sci., 1944, **34**, 97.
10. E. S. E. Hafez, Sexual Season in Ewe Lambs. Nature, 1951, **168**, 1046.
11. J. Hammond and F. H. A. Marshall, Reproduction in the Rabbit, London, 1925, p. 25.
12. C. W. Upp and R. B. Thompson, Influence of Time of Hatching of the Eggs, Rate of Growth of the Chicks and Characteristics of the Adult Female. Oklahoma Agric. Expt. Stat., 1927, Bull. No. 67, pp. 1–36.
13. F. P. Jeffrey and S. P. Platt, Sexual Maturity of Hens. New Jersey Agric. Expt. Stat., 1941, Bull. No. 687, pp. 1–23.
14. O. Riddle, Studies on the Physiology of Reproduction. Amer. J. Physiol., 1931, **97**, 581.
15. E. L. Wiggins, L. E. Casida, and R. H. Grummer, The Effect of Season of Birth on Sexual Development in Gilts. J. Anim. Sci., 1950, **9**, 277.
16. J. H. Prentice, R. G. Baskett, and G. S. Robertson, How Far is the Age of Puberty affected by the Plane of Nutrition on which the Animal is reared? Proc. World's Poultry Congr. (Lond.), 1930, **4**, 242 (22).
17. H. S. Gutteridge, J. M. Pratt, and J. B. O'Neil, The Relative Effect of Nutrition on Poultry. Sci. Agric., 1944, **28**, 240.
18. D. E. Walker, The Breeding Season, Oestrus and Oestrous Cycle in the New Zealand Ewes. University of New Zealand Thesis for M.Sc., 1943.
19. R. H. Watson, Personal communication, Australia, 1950.
20. A. L. Badreldin, Growth and Carcass Percentage in Ossimi and Rahmani Sheep. Cairo, Faculty of Agric., 1951, Bull. No. 3, pp. 1–15.
21. A. F. Khishin, A. L. Badreldin, M. M. Oloufa, and M. A. Kheireldin, Growth, Development and Litter-size in Two Breeds of Rabbits. Cairo, Faculty of Agric., 1951, Bull. No. 2, pp. 1–29.
22. C. D. Squiers, G. E. Dickerson, D. T. Mayer, Factors affecting Litter-size during Pregnancy in certain Strains of Swine. J. Anim. Sci., 1950, **9**, 683.
23. G. L. Robertson, R. H. Grummer, L. E. Casida, and A. B. Chapman, Age at Puberty and Related Phenomena in Outbred Chester White and Poland China Gilts. J. Anim. Sci., 1951, **10**, 647.
24. H. L. Kempster, The Correlation between Sexual Maturity and Egg-production. Mo. Agric. Expt. Stat., 1925, Bull. No. 78.
25. M. W. Buster, The Relation of Rate of Maturity to Egg-production. Cal. Agric. Expt. Stat., 1927, Bull. No. 424.
26. C. W. Knox, Factors influencing Egg-production. II. The Influence of the Date of First Egg Upon Maturity and Egg-production. Iowa Agric. Expt. Stat., 1930, Res. Bull. No. 128.
27. E. T. Engle, R. C. Crafts, and C. E. Zeithaml, First Oestrus in Rats in relation to Age, Weight, and Length. Proc. Soc. Expt. Biol. & Med., 1937, **37**, 427.

(*Received January 13, 1953*)

# PRE-EMERGENCE SEED-BED LOSSES IN GROUNDNUTS AT URAMBO, TANGANYIKA TERRITORY

I. A. S. GIBSON AND P. K. S. CLINTON

(*Overseas Food Corporation*)

FIELD observations carried out between 1949 and 1951 in the Urambo region of the Overseas Food Corporation showed that pre-emergence seed-bed losses in groundnut cultivations were of the order of 30–50 per cent. of seed sown. As these losses presented a major problem in the groundnut cultivations of the region, they were investigated to determine their cause.

The area under cultivation at Urambo at the time of the investigation had been cleared originally from Miombo forest (Brachystegia-Isoberlinia complex), no field had been under crops for more than three years, and all agricultural operations had been mechanized. Our observations were made on production units and the experimental work was done on the Experiment Station of the region. All observations and experiments were made on the groundnut variety Natal Common, unless otherwise stated, as this variety was widely planted in the production areas.

## *Mechanical Injury of Seed in relation to Seed-bed Losses*

*Influence of seed damage on germination.*—Preliminary observations carried out on seeds recovered immediately after mechanical planting showed that although these gave results of 96–100 per cent. in germination tests carried out in the laboratory with a moist filter-paper technique, some damaged kernels were also present in each lot, and such damage might lead to an increased susceptibility of the seed to destruction while in the soil.

Two field experiments were carried out along similar lines but on two different soil types (red sandy loam and red-grey sandy loam) which were designed to compare the effects of four grades of seed damage on seedling emergence these grades were as follows:

i. Whole seed, with no visible blemish.

ii. Partly damaged seed from which some of the testa had been lost or which had suffered some chipping or bruising of the cotyledon.

iii. Seed which had lost all the testa.

iv. Split seed which had lost one cotyledon.

A comparison was also made between the emergence of untreated seed and that dressed with the proprietary mercurial seed dressing, Agrosan GN, applied at a rate of 4 oz. per cwt. of seed, which was included in the designs of both experiments.

Experimental plots were hand-planted with a constant number of seeds (200 per plot), and 14 days after planting (6–7 days after the first appearance of plumules) the emergent plant populations were

[Empire Journ. of Exper. Agric., Vol. 21, No. 83, 1953.]

counted. Samples of the seeds planted were also put through laboratory germination tests, under which conditions germination was high, irrespective of the degree of damage to the seed. The results are given in Table 1.

TABLE 1. *Effect of Seed Injury on Pre-emergence Seed-bed Losses*

| | *Percentage Emergence* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Seed untreated* | | | | *Seed treated with Agrosan GN* | | | |
| *Soil type* | *Seed split* | *Testa lacking* | *Testa partly lacking* | *Seed uninjured* | *Seed split* | *Testa lacking* | *Testa partly lacking* | *Seed uninjured* |
| Red | 34 | 26 | 67 | 89 | 59 | 69 | 92 | 97 |
| Red-grey | 24 | 18 | 48 | 80 | 40 | 38 | 82 | 90 |

| *Significant differences:* | *5% level* | *1% level* |
|---|---|---|
| Red soil | 6·6 | 9·0 |
| Red-grey soil | 5·7 | 7·7 |

These results disclose a close relation between severity of seed injury and failure of emergence. It is also clear that such losses may be controlled to a certain extent by the use of Agrosan GN.

*Causes of mechanical injury of seed.*—As seed-damage had been shown to play an important part in the pre-disposition of groundnut seed to pre-emergence loss, a survey was carried out to trace its source in pre-planting operations. Before planting, seeds normally passed through four main stages, as follows:

1. Removal of seed in shell from the stack and its subsequent passage through the decorticator, where it was shelled and screened for size.
2. Seed treatment: mechanical application of organo-mercurial fungicide (Agrosan GN).
3. Replacement of seed in store and its subsequent transport to the field.
4. Passage through the planter in the course of planting.

To give an index of seed-damage a progressive check of these operations was made by sampling seeds after each stage and counting for each the percentage of split seeds. The results of this preliminary survey are given in Table 2.

TABLE 2. *Damage to Groundnut Seeds by Mechanical Processes*

| | *Split seeds in sample, %* | | *Splitting due to process, %* |
|---|---|---|---|
| | *Before process* | *After process* | |
| Mechanical decortication | 0 | 2·6 | 2·6 |
| Dressing of seed | 2·6 | 3·3 | 0·7 |
| Transport, &c. | 3·3 | 4·6 | 1·3 |
| Planting | 4·6 | 5·1 | 0·5 |

These figures show that the major part of this type of injury arose in the decorticator, although considerable damage also occurred during

other operations. A further experiment has indicated that mechanical decortication not only causes splitting of the seed, but also renders the seed more liable to further splitting as it passes through the planter. Thus, seeds suffered no splitting during hand-decortication, and on passing through the planter only 0·7 per cent. were split, whereas machine decortication caused 2·8 per cent. of a similar sample to split immediately and a further 2·0 per cent. split on passing through the planter.

These conclusions are supported by the results of a further series of counts made for seed injury (including split seed and seed which had partially or totally lost the testa) on seed obtained direct from the decorticator, and from similar seed before and after passing through the planter. The results given in Table 3 represent the means of nine determinations on seeds from the decorticator and seven determinations made from similar material at the time of planting.

TABLE 3. *Damage to Groundnut Seeds by Mechanical Processes. Percentage of Damaged Seeds in Samples*

| | *Seed split* | *Testa lacking* | *Testa partly lacking* | *Total damage* |
|---|---|---|---|---|
| After decortication . . . | 0·9 | 3·2 | 19·8 | 23·9 |
| Before passing through planter . | 2·6 | 4·1 | 23·3 | 30·0 |
| After passing through planter . | 3·5 | 4·6 | 23·7 | 31·8 |

It is clear that the greater part of the total seed-injury occurred during decortication, and that increases in numbers of split seeds are mainly confined to subsequent stages. The difference between the value obtained for numbers of split seeds after decortication in this survey and that obtained in the previous one (Table 2) could be accounted for by the different conditions under which each was taken, as about 2 months elapsed between the first and second determinations.

*Varietal response to mechanical injury of seed.*—A comparison of the type and extent of damage sustained by five varieties of groundnut seed during decortication appears in Table 4.

TABLE 4. *Effects of Mechanical Decortication on Five Varieties of Groundnut Seed*

| *Variety* | *Seed colour* | *Texture of testa* | *Damaged seeds, %* | | | |
|---|---|---|---|---|---|---|
| | | | *Seed split* | *Testa lacking* | *Testa partly lacking* | *Total damage* |
| Natal Common . | Brown | Smooth | 0·1 | 1·7 | 10·6 | 12·4 |
| Kidang . . | Red | Smooth | 0·3 | 0 | 11·4 | 11·7 |
| Arachide Kigan . | Red | Smooth | 0 | 0 | 14·6 | 14·6 |
| Asirya Mwitundi. | Brown-red | Rough | 6·5 | 0 | 11·2 | 17·7 |
| Virginia Bunch . | Red | Rough | 5·8 | 0·1 | 13·2 | 19·1 |

The main difference between varieties appears to be in the greater susceptibility to injury of the varieties with rough testas.

*Miscellaneous Factors Contributing to other Seed-bed Losses*

A single field experiment has shown that differences in *seed-size* within the same variety (Asirya Mwitundi) lead only to small differences in pre-emergence losses, after adjustment has been made for the greater number of seeds sown in the smaller grades by a constant planter-setting. The effects of *planting-depth* have also been investigated in two field experiments, and some evidence has been forthcoming that pre-emergence losses may increase at planting-depths greater than 2½ to 3 in.; but under well-controlled planting conditions these limits should not be reached, and this factor probably has little significance in the field. Laboratory experiments on seeds grown in sand have shown that the emergence of seedlings is retarded at a *moisture level* of less than 30 per cent. of the saturation value of sand. It has also been demonstrated that at a *soil temperature* of 105° F. the growth of seedlings remains unaffected. As Urambo soil conditions at a depth of 1½ in. rarely approach such levels of moisture and temperature it seems unlikely that either of these factors plays any appreciable part in the pre-emergence seed-bed losses of groundnuts in the region.

Evidence remains inconclusive with regard to the effects of *soil type* on pre-emergence losses. The effects of *numbers of seeds* planted per acre have also been studied, and a graded increase in percentage of pre-emergence loss has been noted, which is correlated with an increase in numbers of seeds planted per unit area. Thus, in one experiment an increase in loss from 12 to 23 per cent. was noted over a graded increase in planted population from 37,500 to 112,500 seeds per acre; elsewhere losses rose from 28 to 41 per cent. where the population was increased from 25,000 to 69,000 seeds per acre. It is thought that the explanation of this may lie in the ability of Rhizopus spp. to grow through the soil to a limited extent, thus enabling more seeds to be attacked from a given centre of infection where the frequency of seeds in the soil was at its highest. Further reference to the destruction of seeds in the soil by Rhizopus spp. will be made below.

*Fungi as a Cause of Pre-emergence Losses*

During the earlier part of this work several attempts were made to recover seed after planting and before emergence with a view to obtaining information on the organisms responsible for loss. These observations were all carried out on too small a scale for quantitative work and served only to indicate that a wide range of fungal contaminants became associated with the seed during its early growth, and that damage by insects was on a very small scale.

The fungi recorded were later placed in three main groups as follows:

1. Phycomycetes. In most cases species of Rhizopus, amongst which *R. stolonifer* Ehren. ex Fr., *R. arrhizus* Fischer, and *R. oryzae* Went. & Gerl. were identified.

2. Penicillium spp. and Aspergillus spp., notably *P. funiculosum* Thom., *P. caryophyllum* Dierckx., *A. flavus* Link., and *A. tamarii* Kita.

3. *Aspergillus niger* van Tiegh. and variants.

Organisms in group 1 are characterized by a high growth-rate, compared with members of group 2, and by a soft rotting action on the cotyledons and embryo of the seed. Members of group 2 generally produced a dry rot of the cotyledons, which became marked just before emergence. Group 3 has been separated from the other groups as cotyledonary infections by *A. niger* may lead to the seedling disease known as crown rot [1], and this fungus may thus have an additional significance.

Following these observations, two experiments were carried out on a larger scale in which bulk plantings of seeds were dug up at intervals and examined for contaminants. Randomized block designs were adopted, each comprising six blocks of eight plots each. The two experiments were carried out under identical conditions, resembling those of normal production practice as closely as possible. The variety of groundnut used in one experiment was Natal Common and in the other Mwitundi. Planting was done by machine and the exact number of seeds delivered per plot was calculated by the difference in seed-numbers in the machine before and after planting. At intervals after planting, one plot from each block was sampled to determine recoverable seeds and seedling infection. The dates at which these eight samplings were carried out were so arranged that four of them fell before emergence was complete; in these cases sampling was carried out by digging out and sieving the planted rows with the adjacent soil to ensure recovery as complete as possible. At later dates no digging was carried out, but plants were removed from the soil for ease in counting. Fungal infections were recorded for the pre-emergence period, and were classified in the three groups described above; this field diagnosis was checked by samples taken to the laboratory for microscopic examination. The results of these experiments are given in Table 5.

TABLE 5. *Pre-emergence Losses and Fungal Infections*

*Natal Common*

| | *Plant losses (percentage of original sowing)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Time of examination (days after planting)* | | | | | | | |
| | 2 | 4 | 7 | 9 | 16 | 32 | 58 | 102 |
| Seeds or plants missing | 5·9 | 12·3 | 18·6 | 29·3 | 43·2 | 50·8 | 46·8 | 46·9 |
| Seeds germinated or growing | 68·9 | 70·5 | 74·4 | 66·6 | 56·8 | 49·2 | 53·2 | 53·1 |
| Seeds not growing | 25·2 | 17·2 | 7·0 | 4·1 | .. | .. | .. | .. |
| | *Fungal infections (percentage of total seedlings recovered)* | | | | | | | |
| Group (1) | 1·7 | 8·0 | 16·2 | 14·9 | .. | .. | .. | .. |
| Group (2) | present | present | 0·8 | 0·2 | .. | .. | .. | .. |
| Group (3) | 0 | 0·2 | 9·4 | 9·6 | 19·5 | .. | .. | .. |

TABLE 5 (*continued*)

*Asirya Mwitundi*

| | *Plant losses* (*percentage of original sowing*) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *Time of examination* (*days after planting*) | | | | | | | |
| | 3 | 6 | 8 | 10 | 16 | 34 | 58 | 118 |
| Seeds or plants missing | 9·0 | 34·7 | 40·5 | 33·3 | 67·9 | 66·9 | 69·2 | 69·8 |
| Seeds germinated or growing . . . | 71·1 | 58·0 | 54·3 | 50·6 | 32·1 | 33·1 | 30·8 | 30·2 |
| Seeds not growing . | 19·9 | 7·2 | 5·1 | 16·9 | .. | .. | .. | .. |
| | *Fungal infections* (*percentage of total seedlings recovered*) | | | | | | | |
| Group (1) . . . | 5·4 | 26·6 | 23·8 | 44·0 | .. | .. | .. | .. |
| Group (2) . . . | present | 2·0 | present | 1·2 | .. | .. | .. | .. |
| Group (3) . . . | present | 1·9 | 0·5 | 8·3 | 20·5 | .. | .. | .. |

The results show that losses in plant population have taken place almost entirely during the pre-emergence period, and serve to confirm the importance of this period in the establishment of adequate plant-stands for agricultural purposes. During this period the sharp rise in seedling losses is followed by a similar rise in numbers of seedlings recovered with fungal infections. Of these infections, those falling into group 1 are the most frequent and follow the increase in seedling loss most closely in both experiments. The sharp rise in group 3 infections at emergence has little significance with respect to pre-emergence losses, but may be connected with the onset of crown rot after emergence. In both experiments crown rot losses were low (4–5 per cent.). The rapidity with which seedlings were destroyed in the soil suggested that this was probably due to organisms that had a high growth-rate, such as those included in group 1; this, in connexion with the relationship that has been observed between the degree of loss and incidence of such infections, indicated that the organisms of group 1 were largely responsible for pre-emergence seed-bed losses.

Two small-scale experiments have been carried out to test these conclusions. In the first experiment seeds of Natal Common groundnut were placed in petri dishes on potato dextrose agar, which was then inoculated with one of three Rhizopus spp. (typical of group 1 organisms) to be tested, viz. *R. stolonifer*, *R. oryzae*, and an unidentified species. Before being placed in the dishes the seed was either surface-sterilized with silver nitrate or treated with Agrosan GN seed-dressing. These dishes were incubated for 3 days at about 20° C. in a saturated atmosphere and then the seeds were examined for attack and rotting, with results that are shown in Table 6.

These results show that the fungi used are capable of rotting groundnut seed, and that Agrosan GN provides adequate protection against them.

The second experiment was designed to test the susceptibility of groundnut seeds at various stages after germination to attack by Rhizopus spp. In this case, seeds were germinated under sterile conditions in a moist atmosphere and then inoculated at various stages of

TABLE 6. *Pathogenicity of Rhizopus spp. to Groundnut Seeds*

| *Organism* | *Percentage of seeds with advanced rotting* | |
|---|---|---|
| | *Seed-surface sterilized with silver nitrate* | *Seed treated with Agrosan GN* |
| *Rhizopus stolonifer* . . . | 20 | 0 |
| *Rhizopus oryzae* . . . . | 60 | 10 |
| Rhizopus spp. . . . . | 45 | 10 |

growth by the application of spores of *R. stolonifer* to the cut surface of a cotyledon. The percentage of seeds rotted was recorded 3 days after inoculation. The results of this experiment are given in Table 7.

TABLE 7. *The Effect of Age of Seedling on Susceptibility to Rotting by* R. stolonifer

| *Age of seedling at inoculation (days)* | *Percentage of seedlings rotted* |
|---|---|
| 0 | 90 |
| 2 | 57 |
| 3 | 20 |
| 4 | 11 |
| 5 | 0 |

These results show an increase in resistance of the seedling to rotting with advancing age. This is in agreement with the field results described above, where, although there was a considerable spread of group 1 infections throughout the pre-emergence period, there was no corresponding increase in the rate at which seedlings were destroyed.

The available evidence thus suggests that the greater part of pre-emergence seed-bed losses of groundnuts at Urambo were due to attack by Rhizopus spp. These fungi are common in the soil and are frequently recorded from the seed-coat of groundnuts before planting.

### *Control of Pre-emergence Losses by Seed-treatment with Fungicides*

Evidence has already been presented that demonstrates the efficiency of Agrosan GN in the control of pre-emergence seed-bed losses in groundnuts (Table 1), and in particular the effect of this fungicide against Rhizopus spp. (Table 6). In addition, field data have been collected from experiments to test the relative effects of different seed-dressings applied at different rates of dosage. During 1949 and 1950 two field trials were carried out, one designed to compare the effects of six preparations, each at two dosage rates, and the other to compare the effects of Agrosan GN at four different dosage rates. In both experiments the seed was planted by a machine normally used in production fields; seed-delivery rate was adjusted to plant approximately 55,000 seeds per acre. The results for emergent plant-population counts are given in Tables 8 and 9 respectively.

TABLE 8. *Influence of Seed-dressings on Plant Population*

| *Preparation* | *Rate of application (per cwt. seed)* | *Form of application* | *Seedlings emerged ('000/acre)* | |
|---|---|---|---|---|
| | | | *1949* | *1950* |
| Abavit B. | 2 oz. | Dust | 19·5 | 28·7 |
| | 6 oz. | ,, | 25·8 | 37·1 |
| Agrosan GN | 2 oz. | ,, | 26·1 | 40·7 |
| | 6 oz. | ,, | 28·8 | 48·3 |
| Ceresan M | 2 oz. | ,, | 23·8 | .. |
| | 6 oz. | ,, | 24·1 | .. |
| Panogen | 100 ml. | Liquid | 27·3 | 35·3 |
| | 200 ml. | ,, | 22·8 | 37·3 |
| Mergamma A | 3 oz. | Dust | .. | 42·5 |
| | 8 oz. | ,, | .. | 48·4 |
| TMTD 50% | ½ oz. | Slurry | 16·3 | 40·2 |
| | 1½ oz. | ,, | 18·0 | 39·7 |
| TMTD 80% | ½ oz. | ,, | .. | 30·2 |
| | 1½ oz. | ,, | .. | 34·7 |
| Nil | .. | .. | 12·0 | 13·0 |

| *Significant differences:* | | *5% level* | *1% level* |
|---|---|---|---|
| Between fungicide treatments | 1949 | 2·7 | 3·6 |
| | 1950 | 6·7 | 9·1 |
| Between fungicide and nil treatments | 1949 | 1·9 | 2·7 |
| | 1950 | 5·3 | 7·2 |

TABLE 9. *Influence of Dosage Rates of Agrosan GN on Plant Population*

| *Rate of application (per cwt. seed)* | *Seedlings emerged ('000/acre)* | |
|---|---|---|
| | *1949* | *1950* |
| 0 oz. | 30·7 | 24·9 |
| 2 oz. | 38·7 | 31·9 |
| 4 oz. | 46·0 | 37·9 |
| 8 oz. | 48·8 | 40·7 |

Significant differences: (1950 experiment only) 5% level 3·5; 1% level 4·7.

During 1951 a larger range of preparations was put on trial, one rate of application being used for each compound. The rates of application were applied according to the makers' recommendations with the exception of organo-mercurial preparations, where the rate was adjusted to give a dosage of mercury equivalent to that of Agrosan GN applied at a rate of 4 oz./cwt. of seeds. Analyses were made in the Scientific Department of the Corporation to obtain values for mercury-content of the preparations on which these adjustments were based. This experiment was

carried out using selected whole seeds, of which a known number were hand-planted in each plot of the experiment. The results for pre-emergence losses in this experiment are given in Table 10.

TABLE 10. *Effects of a Range of Seed-dressings on Emergent Plant Populations of Groundnuts*

| *Preparation* | *Active principle* | *Rate of application (per cwt. seed)* | *Form applied* | *Percentage emergence* |
|---|---|---|---|---|
| Aagrano 48 . | Organo-mercurial | 2·4 oz. | Dust | 93 |
| Mergamma B . | Organo-mercurial plus gamma B.H.C. | 4·4 oz. | Dust | 93 |
| Leytosan S . | Organo-mercurial | 2·0 oz. | Slurry | 91 |
| Mergamma A . | Organo-mercurial plus gamma B.H.C. | 4·4 oz. | Dust | 90 |
| Agrosan GN . | Organo-mercurial | 4·0 oz. | Dust | 90 |
| Ziram 76% . | Zinc dimethyl dithiocarbamate | 4·0 oz. | Dust | 90 |
| Ceresan M . | Organo-mercurial | 1·9 oz. | Dust | 89 |
| Abavit B . . | Organo-mercurial | 2·9 oz. | Dust | 89 |
| Fernasan . . | Non-metallic organic compound | 2·0 oz. | Dust | 88 |
| Nomersan . | Non-metallic organic compound | 4·0 oz. | Dust | 88 |
| Zineb 75% . | Zinc ethylene bis-dithiocarbamate | 4·0 oz. | Dust | 87 |
| Thiram 50% . | Non-metallic organic compound | 2·0 oz. | Dust | 87 |
| Thiram 75% . | Non-metallic organic compound | 2·0 oz. | Slurry | 87 |
| Spergon SL . | Non-metallic organic compound | 3·0 oz. | Dust | 86 |
| Phygon XL . | Non-metallic organic compound | 3·0 oz. | Slurry | 86 |
| Panogen . . | Organo-mercurial | 142·5 ml. | Liquid | 85 |
| Ferbam . . | Ferric dimethyl dithiocarbamate | 4·0 oz. | Dust | 83 |
| Nil . . . | .. | .. | .. | 74 |

The results of these experiments show that all seed-dressings on trial gave useful increases in emergent plant populations, and that, on the whole, the organo-mercurial preparations gave a rather better and more consistent protection than did the other fungicides tested. The method of application of the fungicide, whether as a dust or slurry, made little difference. These results are in agreement with those of other African workers [2, 3], and with some work in the U.S.A. [4, 5, 6, 7, 8]. On the other hand, the results of work elsewhere in the U.S.A. have demonstrated that non-mercurial preparations may be superior at times in the protection of groundnut seeds from pre-emergence losses [9, 10]. Phytotoxic effects have been rare in the Urambo experiments; the only compound that has given results suggesting such an effect is Panogen

when it is applied at dosage rates above those recommended by the makers. No indications of phytotoxic effects have been observed with organo-mercurial dusts, although these have been reported elsewhere [8]. Seed-dressing gave no apparent effect on the nodulation of groundnut plants.

*Discussion.*—The experiments at Urambo have made it clear that, in this region, seed-injury is the most important factor contributing to pre-emergence seed-bed losses in groundnuts. It is possible that this is open to control by modification of decorticator design, or by the development of planting seeds in shell. The importance of seed-damage as a factor leading to seed-bed losses has been generally recognized in East and South Africa, and has also been emphasized by Higgins [6] in the U.S.A., but the cause has generally been attributed to faulty planter-adjustment rather than that of the decorticator. Provided that an adequate control of seed-injury can be developed, the range of efficient fungicides already known gives promise of an almost complete control of seed-bed loss of the type studied at Urambo. Up to the time of writing there has been little evidence of 'concealed damage' of groundnut seed grown at Urambo, such as that reported from the U.S.A. [11, 12, 13, 14].

*Acknowledgements.*—The authors are indebted to the staff of the Scientific Department of the Overseas Food Corporation, both at the Experiment Station at Urambo and elsewhere, for their help during the progress of this study; acknowledgement is also due to the Commonwealth Mycological Institute for its assistance in the matter of identifications.

REFERENCES

1. I. A. S. Gibson, Crown Rot, a Seedling Disease of Groundnuts caused by *Aspergillus niger* van Tiegh. Trans. Brit. Mycol. Soc., 1952 (in press).
2. J. C. F. Hopkins, The Importance of Seed-disinfection of Groundnuts. Rhod. Agric. J., 1945, **42**, 432–3.
3. J. Sellschop, Groundnuts. Fmg. in S. Afr., 1947, **22**, 705–12.
4. Anon., Rept. Gal. Expt. Stat., 1943–4, pp. 53–60.
5. Anon., Rept. N.Y. St. Agric. Expt. Stat., 1942–3, pp. 34–43, 53–58.
6. B. B. Higgins, Some Factors affecting the Viability of Peanut Seed. Phytopathology, 1949, **39**, 496.
7. L. Shaw, Results of Seed-treatment tests on Peanuts. Phytopathology, 1942, **39**, 500.
8. C. Wilson, Factors affecting the Efficiency of Peanut Seed Treatments. Phytopathology, 1949, **39**, 500.
9. Anon., Ann. Rept. Agric. Expt. Stat. Florida for year ending June 30, 1945.
10. H. C. Bucha, Seed-treatment as an Aid to the War-time Production of Peanuts. Agric. News Lett., 1942, **10**, 114–22.
11. K. H. Garren, B. B. Higgins, and J. G. Futral, Blue-black Discoloration of Spanish Peanuts. Phytopathology, 1947, **37**, 669–79.
12. —— —— Fungi Associated with Runner Peanut Seeds, and their relation to Concealed Damage. Phytopathology, 1947, **37**, 512–22.
13. C. Wilson, A *Diplodia* Associated with Concealed Damage in Peanuts. Phytopathology, 1945, **35**, 480.
14. —— Concealed Damage of Peanuts in Alabama. Phytopathology, 1947, **37**, 657–68.

(*Received November 18, 1952*)

# THE MECHANICAL THINNING OF SUGAR-BEET

R. W. SHEPHERD

(*Norfolk Agricultural Station*)

*Introduction.*—Today there is an urgent need for economy in hand-labour when singling all root crops and especially sugar-beet. The multi-seed nature of the natural clusters of the sugar-beet 'seed', and the need for a high standard of accuracy when hoeing, combine to make sugar-beet singling more laborious and therefore more expensive than for any other root crop, and it is often difficult to get the hand-labour necessary to do the work before delayed singling takes its toll of yield.

These factors also combine to make efficient mechanical thinning difficult. Of the methods of mechanical thinning cross-blocking or cross-hoeing seemed at one time to be the most promising. Cross-blocking is done by drawing pairs of hoes across the rows of beet at an angle to the drilling with the blades set to cut out the majority of the plants and leave bunches where it is hoped to leave a plant after singling. The positions at which the bunches are left is determined by the setting of the hoe blades and cannot be varied to compensate for gaps in the braird. Since sugar-beet brairds are never perfect and regular some of the uncut pieces of row will not contain plants, but the proportion of these misses can be controlled by varying the size of the pieces of uncut row. As the distance between the hoes is increased, and less of the row is cut out, the proportion of misses will be reduced. For any braird, therefore, the maximum number of bunches that can be left is determined by the row-width and the distance the bunches are left apart in the row, but the proportion that will actually contain plants depends on their size and the regularity of the braird. Accurate measurements can easily be made on any braird to discover what hoe-setting is necessary to ensure a full final plant population.

*Pre-war trials.*—Experiments on cross-blocking were begun at the Norfolk Agricultural Station in 1932 and continued until 1939; further trials were carried out during the war and again in 1949, 1950, and 1951. The pre-war trials were mainly concerned with developing an efficient technique and the various methods used were judged by their effect on the final plant-population. Although the effect of plant-population on yield undoubtedly varies with soil type and with season, it is considered that at least 27,000 roots per acre are necessary at Sprowston to give the maximum yield. Many of the early trials were designed to investigate the optimum row-width and spacing of the bunches in the row and, although they show some seasonal variation, the results suggested that the most satisfactory method was to drill on 14 or 15 in. rows at a seeding of 20 lb. of natural seed per acre and cross-block at right angles to leave bunches at 14 or 13 in. intervals respectively. On these narrow row-widths the final plant populations after cross-blocking were as good as those after all hand-work, but when the row width was increased to 18 in. there was almost invariably a reduction in plant population.

[Empire Journ. of Exper. Agric., Vol. 21, No. 83, 1953.]

These trials were all drilled with natural seed in a cup-feed drill, and since the brairds were rather irregular, large bunches had to be left to ensure a full final plant: in most years they contained an average of over five plants. Because the bunches were so large and the hoeman found difficulty in working on narrow rows, there was seldom any saving in singling time due to cross-blocking except where the men were working on 18-in. rows and then some of the saving was due to the reduced plant-population that usually resulted.

Trials were also carried out at this time to investigate the effect of the size of the plants at the time of cross-blocking, and cross-cultivation, on the yield of the crop. It was shown that the optimum time to cross-block was when the plant had from two to four true leaves. After that stage the plants were likely to be damaged and the yield suffered from the prolonged competition between plants. If cross-blocked too early, however, the smaller plants were liable to be buried and killed, but this depended to a great extent on soil conditions and the equipment used. If the ground was firm and level and if disks were fitted to the hoes, it was possible to cross-block as early as the two-leaf stage without damage. Further work on the effect of bunching showed that when the beet had been cross-blocked in the four-leaf stage they could be left for a further 7 days without any loss in yield due to delayed singling. The trials on the effect of cross-hoeing after cross-blocking showed that it reduced plant-population and seldom gave an increase in yield.

*Post-war trials.*—These were carried out to discover the possibilities of cross-blocking when using precision drills, and rubbed and graded seed. Although 14-in. rows had given the best results in the pre-war trials they proved too narrow for the effective use of machines, particularly during harvesting. Thus the more recent trials were all drilled on 18-in. rows and the bunches were not left more than 10 in. apart, to avoid an undue loss in plant.

In 1949 plots of both natural and 7–11/64 rubbed seed were drilled at three seed-rates using an agitator feed-drill. The low and medium seed rate plots of both seed types had to be cross-blocked to leave 3 in. bunches to ensure a full plant population, whereas 2 in. bunches were large enough on the high seed-rate plots where the braird had fewer gaps. Cross-blocking led to a loss of 3–4,000 plants per acre on all plots and the only real saving in singling time, about 25 per cent., was on the high seed-rate plots which were cross-blocked to leave 2 in. bunches. On the rubbed seed plots the singling time fell as the seed rate was reduced, so that the low seed-rate plot was singled entirely by hand in the same time as the high seed-rate plot was singled after cross-blocking and had nearly 4,000 more plants per acre.

In the 1950 trial one plot was drilled with natural seed at 13½ lb. per acre by a cup-feed drill and another with 7–9/64 rubbed and graded seed at 10 lb. per acre by a precision unit drill. Cross-blocking gave a 30 per cent. saving in singling time over all hand-work, but at the expense of 6,000 plants per acre on the natural seed plot and 4,000 on the precision unit plot: this difference of 2,000 plants was probably a reflection of the more regular braird from the precision drill. Most of

the loss in plant population occurred during the final hand-singling as there was a full population of bunches after cross-blocking.

In the 1951 trial the main treatments were 7–9/64 rubbed seed drilled at 11 lb. per acre in both a precision drill and a cup-feed drill and at 8 lb. in the precision drill only. On both plots drilled with 11 lb. of seed per acre 3 in. bunches were necessary if left at 10 in. intervals but 2 in. bunches were large enough if the total possible number was increased by leaving them at 8 in. intervals along the row. On the plot drilled with 8 lb. of seed the minimum size of the bunches for the two spacings was $3\frac{1}{2}$ and $2\frac{1}{2}$ in. respectively. Part of each main plot was cross-blocked to leave bunches of the necessary size at 8 and 10 in. intervals. Soil conditions were poor on all plots at singling time but were much worse on the all-hand-work plots, which had not had the benefit of the extra cultivation across the rows. Compared with all hand-work, cross-blocking at both hoe settings gave a saving in singling time of between 25 and 30 per cent. on all main plots, but led to a loss of between 3,000 and 5,000 plants per acre. This loss always occurred during hand-singling and was much greater on the plots where the bunches were left 8 in. apart, presumably because this spacing was too narrow for the 6-in. hoes used by the hoemen. On these plots with the 2-in. bunches, however, there appeared to be more single plants than where 3-in. bunches were left, and on adjacent plots that were cross-blocked with hoes set only 1 and $1\frac{1}{2}$ in. apart about one-third of the bunches contained only one plant.

*Discussion.*—The primary aim of any mechanical thinning must be to reduce the hand-labour needed to single the crop without any accompanying loss due to reduced plant, delayed singling, or the presence of weeds or doubles in the crop. During the pre-war trials little saving was achieved and the 14-in. rows investigated then proved unsuitable for the effective use of machinery at other stages in the growth of the crop. These trials did show how valuable cross-blocking could be in extending the singling period without loss in yield, and this fact should be remembered when the beet are growing away from the hoe. All the post-war trials recorded an appreciable saving in singling time from cross-blocking. Part of this saving may have been due to the improved hand-hoeing conditions, the result of cultivation across the rows, but part was undoubtedly due to reduced plant-populations. If the results of the 1950 and 1951 trials are expressed as man hours taken per 1,000 beet left, the saving due to cross-blocking is reduced to about 15 per cent. in 1950 and 5 per cent. in 1951. It is also possible that the practical benefits of cross-blocking may have been exaggerated because the comparison with hand-work has usually been made on a braird that was drilled at a high seed rate for cross-blocking and was too thick for easy hand-work. These results suggest that a real saving in singling time, as distinct from a saving due to reduced plant-populations, will only result from mechanical thinning when a method is devised whereby the machine does more than bunch and actually singles out a proportion of the plants. Thinning the bunches to single plants by hand takes the greater time, for the plants must be isolated from each other and from weeds. The 1951 trials showed

that more plants are isolated if very small pieces of row are left uncut; and are confirmed by studies made in 1952. Accurate counts on a rather thick braird from 7–9/64 rubbed seed showed that if it had been cross-blocked to leave 2 in. gaps, 76 per cent. of the uncut pieces of row would have contained some plants and 32 per cent. would have contained only one plant. If the bunch size had been reduced to 1 in., however, then only 51 per cent. of the bunches would have contained plants, but 52 per cent. of them would have contained a single plant. Whenever large bunches are left there is a greater chance of leaving weeds growing alongside the beet plants and the weeds are more troublesome when singling than are the unwanted beet plants. Since the chance of a miss increases as the bunch-size is reduced, it follows that any reduction in bunch-size must be accompanied by an increase in the number of bunches left. Leaving 2-in. bunches at 8-in. intervals in 1951 was a step in this direction but then 90 per cent. of the bunches left after cross-blocking were required to give a full plant, and the bunches were too close together for the hoeman to leave that number. An alternative approach is to discard all ideas of leaving a bunch only where a plant is required after singling, and to bunch the crop to leave the maximum possible number of very small bunches, hoping that many will contain single plants. For example, a crop on 18-in. rows bunched to leave every alternate 1 in. of row uncut would have a maximum of 174,000 bunches per acre. If only half of these contained plants, but half of those plants were singles, then there would be over 40,000 single plants per acre for the hoeman to select when singling. This method assumes that the single plants are evenly distributed along the row, but it has the advantage that the crop can be thinned by machinery and the discretion of the hoeman asserted in the last stages of singling to ensure a full plant-population. Cross-blocking is clearly of no assistance in thinning on these lines as the normal cross-blocking hoe will not leave the bunches close enough together. It is possible, however, with the recently introduced American machines which work along, as distinct from across, the row. These machines are the logical development of the cross-blocking hoe, but have been critically tested only in this country for one season, and it is too early yet to make any pronouncement upon them.

Every method of mechanical thinning depends for its complete success upon careful cultivations during the preparation of the seed-bed and may be aided by modern developments in the production of precision drills and processed seed. The ideal braird for any form of mechanical thinning must be vigorous, regular, full, and contain a high proportion of single plants. With the exception of certain experimental machines incorporating an electric eye, no machine can adapt itself to the variations of an irregular braird; to deal with irregular brairds either the machine must be set to suit the thinner portions of the row (when insufficient work will be done on the thicker parts), or a loss in plant must be accepted. The regularity of the braird is profoundly affected by the efficiency of the drill, and recent trials at Sprowston suggest that some modern precision drills are more efficient than the older cup-feed types; but a well-prepared seed-bed is equally, if not more,

essential to ensure that the seeds germinate and develop evenly in every row. A full braird is necessary if small bunches are to be left and this factor is primarily determined by the seed rate sown, but it also depends on good seed bed conditions so that all the seeds sown may germinate and grow. A high proportion of single plants in the original braird will improve the efficiency of mechanical thinning, since no machine can be expected to thin out the clusters of plants produced from natural seed. Rubbed seed, however, will produce many more single plants than natural seed, and better results accrue from mechanical thinning when this type of seed is used intelligently.

(*Received April 8, 1953*)

# BREEDING ALFALFA IN CANADA[1]

J. L. BOLTON[2] AND M. W. CORMACK[3]

SOME idea of the growing importance of alfalfa in Canada may be gained through a study of data recently published by the Dominion Bureau of Statistics [1]. During the past 40 years the total acreage of all hay crops, including alfalfa, has remained relatively stable with estimates varying from 8 to 10·5 million acres. Alfalfa, however, showed enormous increases, for example, the estimated acreages in pure stands were 55,000 in 1910, 750,000 in 1930, and 1,547,000 in 1950. Estimates of acreages of alfalfa grown in mixture with grasses are not available, but they would be large and might even exceed those for pure stands.

Much of the credit for the present popularity of alfalfa as a forage crop in Canada is due to the production of improved varieties. A recent estimate [2] places the total value of improved alfalfa varieties at a minimum of $180 million. The rate of this contribution from plant-breeding is unlikely to decline; in fact, even larger returns are in prospect if breeding projects now in progress are successful.

## *Organization of Projects*

Breeding projects are initiated and carried out either by provincial universities or by institutions supported by the Federal Government. Private concerns are not active in this type of plant improvement. A good example of provincial participation is the production of Ferax by the University of Alberta. This variety resulted from an intensive breeding programme for high seed yield that extended over an 18-year period [3].

A very extensive programme of plant improvement is operated by the Canada Department of Agriculture through its Experimental Farms Service and Science Service. Alfalfa breeding is part of the responsibility of the Forage Plants Division of the Experimental Farms Service. This division consists of a central office and laboratories at Ottawa, Ontario; a branch laboratory in western Canada at Saskatoon, Saskatchewan; and forage crops sections at most of the experimental stations across Canada. Co-ordination is attained by having all projects authorized through the headquarters of the Division. Lists of staff, personnel, and authorized projects are included in the latest progress report of the Division [4].

The Science Service of the Department of Agriculture is responsible for most of the federal research dealing with plant diseases and insect pests. Co-operation between the Experimental Farms and Science Services is well illustrated by projects on breeding for resistance to bacterial

[1] Joint contribution from the Division of Forage Plants, Experimental Farms Service, and the Division of Botany and Plant Pathology (Contribution No. 1274), Science Service, Department of Agriculture, Ottawa, Canada.

[2] Agricultural Research Officer in charge of alfalfa investigations, Forage Crops Laboratory, Saskatoon.

[3] Officer-in-Charge, Laboratory of Plant Pathology, Lethbridge, Alberta.

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953.]

wilt and winter crown rot. More details of these projects are given later in this paper.

Co-operative arrangements between the Federal Government and provincial universities are not uncommon. Thus Federal assistance aided a breeding project at the University of British Columbia and the variety Rhizoma has been released [5]. At the University of Saskatchewan a mutually satisfactory agreement between the Federal Government and the university has been in effect for 20 years. Under this agreement the university provides office and laboratory accommodation and facilities for field experimentation. In return, the branch laboratory of the Forage Plants Division conducts all research on forage crops for the university and is responsible for providing suitable instruction on forage crops for students in agriculture.

Within the Experimental Farms Service, co-operation normally consists of reciprocal testing of promising selections and synthetic combinations. For example, a station in northern Saskatchewan is well situated for determining seed yield; resistance to bacterial wilt is tested under irrigation in southern Alberta, and experiments on drought-tolerance are carried out in southern Saskatchewan.

Another important phase of the co-operative work has to do with the United States Department of Agriculture. Friendly relationships between workers in Canada and the U.S.A. have always existed and have resulted in much informal exchange of information and material. In 1934 the Alfalfa Improvement Conference was organized in the United States to provide a co-ordinated approach to the exchange of ideas and the dispersal of information from uniform trial data. For several years Canada has been an active participant even to the extent of acting as host to the Conference in 1950.

### *Objectives and Progress*

Alfalfa in Canada is grown under rainfall varying from 10 to 60 in. annually, on soils decidedly acid to decidedly alkaline in reaction, and in areas where winter temperatures may never reach 0° F. to those where −50° F. is not uncommon. Naturally, this wide variation in environment has important effects, both direct and indirect, on a breeding programme. This section attempts to describe the main objectives of Canadian alfalfa breeders and to indicate the progress that is being made.

1. *Winter hardiness.*—Canadian alfalfa must be winter-hardy for two main reasons. First, climatic conditions in Canada demand hardiness, except for small acreages in parts of British Columbia and in the Niagara peninsula. Secondly, about 70 per cent. of the Canadian production of alfalfa seed is sold in the U.S.A., where it is advertised as 'northern grown winter-hardy seed'. A satisfactory level of resistance to cold has been attained in the standard varieties, Grimm and Ladak. Thus, although no breeding project is devoted entirely to winter hardiness, all must provide for its maintenance or increase.

2. *Forage yield.*—Like winter hardiness, forage-yield requirements are fairly well met by standard varieties. Thus, new selections should at

least equal the yield of the varieties they are to replace if the demands of the grower are to be satisfied. Perhaps more attention should be given to the distribution of yield. In many parts of Canada a short growing-season or a dry summer period limits the alfalfa hay crop to one cutting. These areas favour a variety like Ladak where the high yield of the first cutting is followed by slow recovery or partial dormancy. Areas with a long growing-season, and especially if irrigation water is available, favour the Grimm variety that recovers quickly after cutting. Quick recovery can be useful in advancing the final date of harvest. Grandfield [6] has shown that late harvesting may have bad effects on winter survival and subsequent forage yield.

3. *Seed-yield.*—High seed-yield ensures adequate supplies of seed at reasonable prices. These are important considerations in certain parts of Canada where farmers have to be persuaded to grow alfalfa or must be convinced of the superior value of a new variety. Ferax represents an increase in seed-yield [3], but the variety is unsatisfactory in other respects. At the Forage Crops Laboratory, Saskatoon, the results of several years of selection had to be discarded because of self-tripping types, a character that tends to reduce seed-yield in advanced generations, at least when combined with self-fertility [7]. However, later work at Saskatoon [8] with other source material is very promising. At Swift Current, Saskatchewan, selection is under way for non-shattering types among hybrids between *Medicago falcata* L. and common alfalfa. Satisfactory progress is being made.

4. *Resistance to diseases.*—Bacterial wilt, caused by *Corynebacterium insidiosum* (McCulloch) Jensen, is a common disease which has greatly shortened the life of alfalfa grown under irrigation and in areas with a relatively high rainfall. This disease has been established since 1938 in the irrigated sections of southern Alberta, where it has restricted the use of alfalfa to short rotations [9, 10], and has ruined the formerly profitable seed production in parts of these districts. It has gradually spread into the central and northern sections of Alberta and Saskatchewan, but present indications are that the damage may not become of major importance in these non-irrigated areas where the annual precipitation is 18 in. or less. The disease has recently become widely distributed and destructive in many sections of British Columbia, Manitoba, Ontario, and Quebec. Grimm and other common varieties are highly susceptible to bacterial wilt. The partially resistant variety Ladak is only of temporary value and the wilt-resistant varieties Ranger and Buffalo, developed in the U.S.A., are not sufficiently winter-hardy in Canada. The objective of the present breeding programme, started in 1946, is to combine a high degree of wilt-resistance and other desirable characteristics in strains adapted to the Canadian climate. Progress has been satisfactory and it is hoped that a variety can be released within 5 to 10 years.

Winter crown rot or snow mould, caused by an unidentified fungus, is, at present, the most destructive disease of alfalfa in the central and northern areas of Alberta and Saskatchewan [11]. For example, 62 per cent. of the alfalfa stands examined in west-central Alberta during a

6-year period were infected and the average estimated damage was 10 per cent. This disease also occurs in Manitoba and British Columbia, but it has not yet been reported from other areas. The fungus kills or weakens the plants beneath the snow during the first thaw in the late winter or early spring, causing damage which is frequently confused with winter killing. All standard varieties of alfalfa as well as many other legumes and grasses are highly susceptible [12]. *Medicago falcata* and derived varieties are being used as sources of resistance [13], and a resistant variety should be released within five years.

Crown bud rot is a recently described disease complex of alfalfa that is widely spread in the irrigated areas of southern Alberta [14]. This disease develops during the growing season and causes a progressive deterioration of stands after the first year. Varietal tests for resistance to this disease are in progress.

Stem- and leaf-diseases also occur in all the alfalfa-growing areas in Canada and must be considered in the breeding programme. Black stem and leaf spot, caused by *Ascochyta imperfecta* Peck, is particularly prevalent and destructive in the northern seed-growing areas of Alberta [15]. In Saskatchewan it can also cause severe damage to alfalfa areas left for seed. Difficulty is being experienced in obtaining definite resistance to this disease.

5. *Tolerance to drought.*—A drought-tolerant, cold-resistant, perennial legume is badly needed in western Canada. Approximately 23 million acres of the brown soil zone in Saskatchewan and Alberta are classed as non-arable grasslands [16, 17]. Moisture efficiency is low, due to low rainfall and high evaporation, and cultivation for cereal production is unprofitable. Part of this land is too hilly or too stony to cultivate but much of it could be broken and seeded to a mixture of cultivated grasses and legumes. Experiments show that crested wheatgrass, *Agropyron cristatum* (L) Beauv., has about twice the carrying capacity of native grassland. If alfalfa is combined with the grass, productivity is doubled again [18].

Introductions of yellow-flowered alfalfa, *Medicago falcata*, from Siberia provided parental types for a breeding project. This species shows exceptional cold-resistance and will persist under extreme drought. Unfortunately, it shatters its seed almost as soon as it ripens. About 1938, *M. falcata* and the Ladak variety of *M. sativa* were crossed. There are no fertility barriers concerned with this cross and selection has aimed at a combination of the hardiness and drought-tolerance of *M. falcata* with the non-shattering and high seed-yield characteristics of *M. sativa*. Progress has been satisfactory and an alfalfa variety for drought areas is a definite prospect within a few years.

6. *Resistance to grazing.*—Common varieties of alfalfa do not stand grazing well. The crowns are exposed and it is thought that tramping by livestock injures them. Types of *M. falcata* with crowns below the surface of the ground and with a creeping-root habit were introduced and described some years ago [19]. What appears to be the same type was rediscovered about 1936 at the Experimental Station, Swift Current, in southern Saskatchewan. The possibilities of a creeping-rooted

alfalfa, especially as a pasture legume, were realized and a breeding project was initiated.

Crosses between creeping-rooted *M. falcata* plants and selected plants of *M. sativa* (Ladak and Grimm varieties) show that the $F_1$-progeny plants may be more vigorously creeping than either parent. This situation continues in filial and backcross generations. Evidently it is not an expression of heterosis but rather a result of transgressive segregation. Backcrosses to *M. sativa* show that it is possible to produce *sativa* types with the creeping-root habit.

In addition to persistence under grazing, creeping-rooted types have other advantages. Thinly seeded stands gradually improve—an important characteristic in dry areas where complete stands are hard to establish. Another possibility is a reduction of bloat hazards. This may occur through a more homogeneous mixture of legume and grass, and through selection of slow-recovery types to correspond more closely with the development of the grass component of the pasture mixture.

Results to date indicate that the drought-tolerant variety referred to in a previous section will also be creeping-rooted. Less work has been done with quick-recovery types suitable for hay and pasture outside of the drought areas, but a start has been made with a backcross programme to develop *sativa* types with resistance to bacterial wilt.

7. *Tolerance to acid soils.*—Poor establishment, reduced growth, and short life characterize alfalfa stands on acid soils. Fortunately, selection may be effective. Clonal lines and even varieties show a differential response to level of soil acidity. A breeding project has been authorized and work is under way on the experimental stations at St. Anne de la Pocatiere, Quebec, and Nappan, Nova Scotia. Up to the present, progress has been limited to the development of suitable selection techniques.

### *Selection Methods*

Methods of selecting alfalfa vary if a plant is to be judged directly or in terms of its progeny. Direct selection will be effective only if the character in question is highly heritable and then only if accurately screened. Unfortunately there are no reports of extensive studies on heritability in alfalfa, and to accept results from other species might be misleading. Thus the concept of heritability cannot yet be fully utilized. Accurate screening, however, cannot be stressed too often. The personal judgement of the plant breeder should be supplemented, wherever possible, by modern experimental methods. For example, adequate replication by means of stem-cuttings will reduce experimental error, and lattice designs are likely to increase precision.

The Canadian programme combines direct testing of clones with the progeny-performance method. For the most part, individual plant performance is used to reduce the original population to a size where progeny methods can be used for more critical determinations. A good example is a report on selecting for seed-yield in alfalfa [8]. From random populations of Grimm and Ladak, 107 plants were selected by visual estimation of pod-setting. These plants were then critically

examined for number of seeds per pod and 13 of the best were retained. All 13 selections were diallel crossed and the resultant progenies grown and tested for seed-yield in a field experiment. When the data obtained were examined, it was found that 11 out of the 13 parents produced progenies that outyielded the original varieties. This is a tribute to clonal selection by pod-setting and seeds per pod. However, the average progeny yields of the 13 parents varied from 166 to 309 lb. of seed per acre: an excellent illustration of the value of progeny performance in making final selections.

For evaluation by progeny, diallel crossing as outlined by Jenkin [20] may be highly effective, and certainly reveals specific combining ability. However, it is impractical for more than a few plants, due to the large number of crosses. A modification whereby a few selected parents are crossed with all plants to be tested has been found useful in selecting for the creeping-root habit of growth at Swift Current, Saskatchewan.

Probably the most widely used method of progeny-testing alfalfa is by polycrosses as described by Tysdal *et al.* [21]. It is particularly effective if large numbers of selections must be evaluated. Each plant under test is clonally propagated and the clones are set out in a replicated polycross nursery for seed production. Seed from different clones of each plant is bulked and used for a progeny test; before bulking, data from the clonal replicates may be compared and used to reduce considerably the number of plants to be progeny-tested. A test of the method [22] indicates that polycross progenies provide a reliable estimate of general combining ability when compared with diallel crossing and with variety top-crossing.

### *Special Techniques*

1. *Screening for disease-resistance*—Tests for resistance to bacterial wilt and winter crown rot are centralized in disease nurseries located in areas where conditions are favourable for the development of these diseases. A wide range of clonal and seedling material, including varieties, selections, and progeny from crosses of various types, is co-operatively tested in these field nurseries.

The bacterial-wilt nursery is located at the Experimental Station, Lethbridge, Alberta, where Mr. R. W. Peake, Head of the Forage Crops Section, has co-operated in the development of methods. Rooted cuttings and seedling plants grown for at least two months in the greenhouse during the winter are inoculated immediately before being transplanted into the field nursery in May. The roots are washed, trimmed, and immersed for 30 minutes in a suspension of the wilt organism. Ten rooted cuttings from each parent clone and 20 or more seedlings from each cross are inoculated and planted as a group in rows 3 ft. apart. To eliminate escapes, each plant is reinoculated in the fall by hypodermic needle injection slightly below the crown. Disease development is encouraged by excessive irrigation and by frequent cutting of the tops. Final notes are taken after the plants have been in the nursery for one to two years, depending upon the rapidity of disease development. A tractor-drawn blade is used to cut the roots off about 4 in. below ground

so that the plants can be lifted out. Each plant is thoroughly checked for infection by peeling all of the bark from the root. With clonal selections, a zero tolerance is used and the line is discarded if any plant shows a trace of infection. In seedling lines, wilt-free plants from populations with relatively little infection may be selected for further testing. The percentage of disease-free plants is determined and, in some tests, each plant is rated for infection by means of a numerical scale (0–5). Attempts are being made to improve methods of inoculation and to develop a greenhouse test which will speed up the elimination of wilt-susceptible plants.

The winter crown-rot nursery is located at the Dominion Laboratory of Plant Pathology, Edmonton, Alberta. In most tests [12] the material is planted in uniformly infested land where a stand of susceptible alfalfa has just been killed. This is done by applying inoculum to the soil near the crowns of the plants in the fall. Nearly all plants in stands thus treated are dead the following spring. The plant remains are thoroughly mixed through the upper soil with a roto-tiller to obtain uniformly infested land. Test material planted in this land will grow normally during the first season. The percentage of plants killed as a result of winter infection is determined in the following spring and all plants are given an infection rating (0–10 scale) based on the extent of rotting of the crown buds and tissues. Attempts are being made to develop a more rapid method of testing alfalfa for resistance to winter crown-rot in controlled-temperature rooms at Lethbridge.

2. *Isolation plots.*—A major difficulty in alfalfa breeding is the production of small, isolated, increase plots. Where seed of several single- and multiple-cross combinations must be grown for testing, the problem becomes particularly acute. In western Canada two general methods have been used: space isolation and isolation under cages.

Space isolation is preferred since it closely approximates to field pollination conditions. No experiments have been conducted to determine the distance necessary to prevent cross-pollination. However, complete lack of contamination, though desirable, probably is not necessary where seed is to be used only for progeny tests. At Saskatoon, adequate isolation is thought to have been obtained with plots 10 ft. square one-eighth of a mile apart and located along a railway right-of-way. The railway fence provided protection from large animals. However, some damage occurred from small rodents and from insects, particularly grasshoppers. Yields of seed were satisfactory except where the plots were damaged.

Isolation under cages has been tested at Saskatoon. Screen wire-cages $4 \times 4 \times 4$ ft. were constructed and placed over small plots of alfalfa. As many as 16 plants or clones were set out under each cage. Pollination was effected by honey bees. Shortly before flowering started one frame of brood in all stages and two frames of honey were placed in a 3-frame hive. A tunnel between the hive and the inside of the cage provided the only outlet for the bees. There was a high mortality of the older bees during the first few days, but younger bees and those newly emerged easily accommodated themselves to the cages and proceeded

to work the alfalfa flowers. The average yield of seed from 34 cages was 100 gm., i.e. about 600 lb. per acre. Larger but more costly cages have been used [23] to cover an area of about 240 sq. ft. and to contain a full colony of honey bees. The latter type may be necessary where much larger quantities of seed are required.

Cages have distinct advantages over space-isolated plots. Isolation is complete, and a large number can be concentrated in a small area near headquarters. On the other hand, seed from under cages may not be comparable to that produced under open pollination. At Saskatoon, the average cross-fertilization of alfalfa under open pollination has been reported to be 94 per cent. [24]. In a later experiment, also at Saskatoon, seed from 13 different cages was tested by recording the flower colour of the progeny of a white-flowered plant growing in each cage. The cross-fertilization so determined varied from 25 to 81 per cent. with an average of 48. Still another experiment compared seed produced under cages with hand-crossed seed. The result was a lower yield-level for the progeny of the plants under cages. Evidently more experimental work is needed to decide the merits of cage isolation.

3. *Generation increase.*—In many parts of Canada the growing-season is so short that there is barely time for alfalfa to flower and mature seed. This means that a crop must be established one year and seed harvested the next. If a line must be increased in a certain environment or if a considerable amount of seed must be produced, then the delay occasioned by two years per generation is unavoidable. Often, however, natural increase is not mandatory and relatively small lots of seed are sufficient, for example, original crosses, crosses for diallel combinations, and crosses for the first synthetic increase (syn 1). At Saskatoon, parent plants are transplanted to the greenhouse in September or October. Flowering starts in November or December and seed is ripe in January. This seed can be germinated immediately if dormancy is broken as described by Aughtry [25]. Seedlings from February plantings can be transplanted to the field early in May and, even at Saskatoon, will mature seed in that year. Another possibility for rapid increase is through co-operation with workers in southern areas, or in the Southern Hemisphere, where a crop may be grown during the Canadian winter season. Proper attention to generation-increase can appreciably shorten the number of years necessary to complete alfalfa-breeding projects.

4. *Asexual propagation.*—The propagation of alfalfa by crown- or stem-cuttings is an important breeding technique. Clonal replication is used to evaluate parent plants and to obtain polycross seed for progeny tests. Later in the breeding programme selected parents may be cloned and set out in isolated plots to produce syn 1 seed, or even propagated to the extent required for the production of commercial hybrid seed. A method of rooting stem-cuttings in running water has been used successfully at Saskatoon [26]. Temperature of the water should be not less than 60° F., and the depth shallow, with the troughs sloped so that all of the water is constantly moving. By this method, which can be adapted to large-scale production, cuttings are rooted in about 11 days.

Another method of propagation has proved very satisfactory in locations where water-temperatures or other unsatisfactory conditions preclude the use of running water. The cuttings are placed in a 1-in. deep layer of sand on top of loam soil in flats or beds. The flats are kept covered with moistened cheesecloth until the cuttings start to root. The rooted cuttings can be left undisturbed until ready for use.

In the process of rooting stem-cuttings from several hundred plants, considerable differences in ease of rooting have been observed. This is important, and easily rooted plants should be selected, especially if commercial hybridization is visualized where extensive clonal propagation may be required.

5. *Crossing and selfing.*—A rapid method of making artificial crosses is useful for breeding work; for example, appreciable amounts of seed of the first synthetic generation may be obtained from artificial crosses; or test crosses to obtain seed for progeny ratings can often be made in the greenhouse, thus saving the trouble and expense of space-isolation plots or cages.

Where complete emasculation is required, the alcohol method [27] is satisfactory, although low seed-sets will be obtained. Good emasculation and better seed-setting occurs if the banner petal is clipped, the tripping mechanism released, and the pollen removed by blowing or suction from the stigma and filaments before the stigmatic membrane is ruptured. The simplest method is to disregard emasculation and rely on differential pollen-tube growth between self and foreign pollen to effect cross-fertilization. In one experiment [8] a large number of reciprocal crosses were made between white- and coloured-flowered parents. Pollen was traded back and forth between two parents by tripping alternate flowers on to the same toothpick. Although no emasculation was attempted almost complete cross-fertilization resulted.

Selfing usually is accomplished by removing all unopened flowers and covering the branch with a brown paper bag. Later, the bag should be manipulated to effect tripping and pollination. In the greenhouse, where insects are excluded, bagging has not been found necessary. Since the tripping process forces the stigma tightly against the banner petal, there would seem to be little chance for cross-pollination after tripping.

6. *Yield determination.*—Evaluation for seed and forage yield can be time-consuming and costly, especially if many lines are under test. Several modifications of normal procedures have been tested at Saskatoon and have given reliable results particularly for preliminary screening.

Instead of determining actual seed-yields by harvesting, threshing, cleaning, and weighing, a rating based on pod-setting is used. Plots are scored from one to nine where one is the best pod set and nine is almost sterile. Zero is reserved to indicate no information such as in the case of missing or badly damaged plots. Several comparisons between actual and rated seed-yields have been made, and highly significant correlation coefficients ranging from $r = 0{\cdot}76$ to $r = 0{\cdot}96$ have been found. Independent records from different observers have agreed closely.

Much of the labour and expense of determining forage-yield lies in the dry-matter analysis. Green weights used directly or converted to dry matter on the basis of a few random samples give a close approximation of actual dry-matter values. The correspondence is especially good where strains of the same crop are compared, as in a breeding programme [28].

If both seed- and forage-yield data are required, and if it is not possible to seed duplicate experiments, considerable information can be obtained by recording straw-yields. The plots are harvested when the seed is mature, air-dried, and then weighed and threshed. Air-dry weights minus seed-weight will approximate forage-yield. A highly significant correlation coefficient of $r = 0{\cdot}76$ was obtained at Saskatoon where straw-yields were compared with forage-yields harvested at the correct stage for haying. Differences in stand from sampling at the two dates and other sampling errors undoubtedly introduced some variation into the above comparison, and it is believed that the true relationship is closer.

### *Methods of Breeding*

1. *Mass selection.*—In eastern Canada, Ontario Variegated was selected at the Ontario Agricultural College, Guelph, Ont., and was released about 1910. Some 10 years later Grimm 451 was released by the University of Saskatchewan, Saskatoon, Sask. Both varieties were the product of mass selection and winter hardiness was a primary consideration. Both have been highly successful in surviving Canadian winters in their respective areas and have given satisfactory seed- and forage-yields. Other attempts to improve seed- and forage-yield by mass selection appear to have produced nothing superior to standard varieties. The reason for the failure is not clear, especially in view of the success obtained with a supposedly complex character such as winter hardiness. It may be an illustration of the value of effective screening. Severe winters occur often enough in most parts of Canada so that cold-susceptible types are largely eliminated. No such set of natural conditions operates to sort out superior genotypes for seed- and forage-yield. Thus, in making selections, the plant-breeder may have relied too much on personal judgement insufficiently supported by experimental data. If intensive methods of evaluating clones are developed, mass selection may yet prove effective. On the other hand seed- and forage-yield may be so strongly influenced by environment that more intensive selection methods involving progeny performance may be necessary to produce results.

2. *Single plant increase.*—The increase of single-plant lines occasionally has been used in alfalfa improvement. Grimm Sask. 666, bred at the University of Saskatchewan, Saskatoon, and released in 1925, resulted from increasing the open-pollinated progeny of a single plant selected for high seed-yield. The hardiness and forage-yield of this strain have been equal to the parent Grimm but superiority for seed-yield has not been proven. The Viking variety is of similar origin and was released in 1940 by the Forage Crops Laboratory, Saskatoon. It was selected for extreme cold resistance and has proved to be especially

winter-hardy in subsequent years. Viking shows a slight advantage in forage-yield over Grimm but no advantage in seed-yield. The idea of increasing single-plant lines probably was borrowed from breeders of self-fertilized cereal crops. It appears to offer little as a means of improving alfalfa.

3. *Maternal-line selection.*—This method of forage crop improvement was first proposed by Fryer [29] and applied by him to alfalfa. The procedure involves a succession of 4-year cycles. In each cycle about 80 open-pollinated progenies are examined and about 80 of the best plants from the best progenies are retained. These selected plants are allowed to intercross and the resulting seed is the final product of that particular cycle. After three cycles of maternal-line selection for high seed-yield, the variety Ferax was released by the University of Alberta, Edmonton, Alta., in 1941. Subsequent yield data from experiments at several points in Canada have definitely established the superiority of Ferax in seed-yield as compared to standard varieties. Unfortunately, forage-yield appears to have been sacrificed to some extent and the variety is not suitable in its resistance to disease. It is significant, however, that Ferax probably represents the first evidence of real progress in breeding for seed-yield and that it was produced by a breeding method that made use of progeny performance.

4. *Synthetic combinations based on progeny performance.*—Synthetic combination based on progeny performance has become widely accepted in Canada as a method of breeding alfalfa since the contributions of Tysdal and his co-workers to the subject some 10 years ago. Their polycross method of testing general combining ability enables a large number of selections to be tested both as clones and by progeny performance. Thus a system of screening is proposed which is actually progeny performance superimposed upon a much-improved technique of mass selection. The general procedure can be summarized as follows:

1. Selection of a large number of parent plants and clonal propagation of each plant.
2. A replicated test of clones in a polycross nursery, followed by the elimination of obviously poor selections.
3. A polycross progeny test using seed from the polycross nursery; the data from this test to be used to reduce the number of selections to a few of the best.
4. A test of specific combining ability of the selected plants from (3), using diallel or test crosses.
5. Isolated increase of synthetic combinations of plants based on information obtained from (4).
6. Replicated experiments comparing synthetic combinations with standard varieties.

The above system of selection and recombination or slight modifications of it is in use particularly in western Canada. It has not been operated long enough to have resulted in the release of varieties. However, the results being obtained with characters such as seed- and forage-yield, disease resistance, and the creeping-rooted character, are very

promising. It seems likely that as experience accumulates the method will become a standardized procedure for alfalfa improvement, and probably also for the improvement of other cross-pollinated, perennial crops.

5. *Commercial hybrids.*—The production of commercial hybrids of alfalfa has not gone beyond the experimental stage. The use of self-sterility to produce commercial hybrids was first proposed by Tysdal *et al.* [21]. A modification was suggested by Bolton [8] and recently Armstrong [30] has presented pertinent data on self-sterility as it may affect the production of commercial hybrids. Theoretically the hybrid method appears to be sound. It may be that hybrid combinations, however, will not have sufficient superiority over synthetics to warrant the additional labour and expense of growing hybrid seed. Information on this point should be forthcoming before long, since wherever specific combining ability is tested in the process of selecting parents for synthetic combinations the same selections will have an alternate use as commercial hybrids. Thus critical comparisons between synthetic and hybrid combinations will be possible.

## *Discussion and Conclusions*

Before concluding this paper it may be worth while to consider what trends are likely to develop in the future. The organization of alfalfa-breeding research in Canada certainly is not perfect. Difficulties still exist and often they are related directly or indirectly to the great distances between points in eastern and western Canada. However, there is fairly adequate provision for co-operative effort and for the exchange of information. Workers in one section of the country usually are well informed on projects at other institutions. This tends to avoid unnecessary duplication and to ensure that favourable environmental conditions for screening are fully utilized. It seems likely that future breeding problems can be accommodated under the present system, especially as it may continue to improve.

Perfection is elusive and plant-breeding problems seldom are completely solved. Thus selection for characters such as yield and hardiness will continue. It may well be, though, that the major effort will shift to new problems or to new approaches to old problems. For example, the discovery of the creeping-rooted character in alfalfa provides an effective means of obtaining grazing resistance. Associated as it is or can be with drought-tolerance, the creeping-root character may well revolutionize the use of alfalfa for pasture in Canada as well as in many other countries. Bloat in ruminants is a condition that has greatly hindered the use of alfalfa as pasture. Perhaps it is not too much to expect that when the agents causing bloat are identified, selection and breeding may prove an effective control. Breeding to alter the chemical composition of alfalfa is an almost untouched field, even though genetic variations of protein and vitamin content have been demonstrated. The success of honey bees as pollinators of alfalfa in parts of the United States may be associated with high temperatures and thus ease of tripping. Perhaps the self-tripping character can be modified to serve the same purpose in the north that high temperatures effect in the south.

But no matter how pressing a problem may be, its solution will be delayed unless good techniques of selection and breeding are known. Fortunately progress is being made. The alfalfa breeder now realizes that he is working with a cross-pollinated, entomophilous plant and that methods adapted to self-pollinated, anemophilous crops are often unsuitable. The importance of progeny performance as a method of selecting parents is widely accepted. At the same time it may be wise to reconsider mass selection. If worthwhile initial improvements are obtained by the application of accurate screening to mass populations, then the efficiency of the slower and more costly progeny method will be increased.

In spite of a better understanding of the basic principles underlying alfalfa breeding, a number of important problems remain. Should selected parent plants be combined as hybrids or as synthetics? What is the minimum number of unrelated selections that can be combined in a synthetic to give maximum effects in advanced generations? When these and similar questions are answered it should be possible to standardize alfalfa breeding. Only then can progress be expected similar to that obtained in crops such as wheat or corn.

## REFERENCES


1. Dominion Bureau of Statistics. Handbook of Agricultural Statistics. Part I. Field Crops. D.B.S . Reference Paper, 1951, No. 25, 186 pp.
2. J. L. Bolton. Alfalfa Breeding. Agricultural Research in Canada. Published by Agric. Institute of Can., 1952, 65–71.
3. J. R. Fryer. Ferax Alfalfa. Univ. Alberta, Dept. Ext., 1943, Press Bull., **28,** 5–6.
4. Canada Dept. of Agric., Progress Report, 1937–48. Division of Forage Plants, Experimental Farms Service, 1950, 99 pp.
5. R. A. Nilan. Rhizoma Alfalfa: Chromosome Studies of the Parent Stock. Sci. Agric., 1951, **31,** 123–6.
6. C. O. Grandfield. Food Reserves and their Translocation to the Crown Buds as related to Cold and Drought Resistance in Alfalfa. J. Agric. Res., 1943, **67,** 33–46.
7. T. M. Stevenson and J. L. Bolton. An Evaluation of the Self-tripping Character in Breeding for Improved Seed Yield in Alfalfa. Empire J. Expt. Agric., 1947, **15,** 82–88.
8. J. L. Bolton. A Study of Combining Ability of Alfalfa in relation to Certain Methods of Selection. Sci. Agric., 1948, **28,** 97–126.
9. M. W. Cormack. Bacterial Wilt of Alfalfa. Can. Dept. Agric., 1943, Multilithed Circ., 4 pp.
10. F. R. Jones. Bacterial Wilt of Alfalfa and its Control. U.S.D.A., 1941, Circ., No. 573.
11. M. W. Cormack. Winter Crown Rot or Snow Mold of Alfalfa, Clovers, and Grasses in Alberta. I. Occurrence, Parasitism, and Spread of the Disease. Can. J. Res., C, 1948, **26,** 71–85.
12. —— Winter Crown Rot or Snow Mold of Alfalfa, Clovers, and Grasses in Alberta. II. Field Studies on Host and Varietal Resistance and other Factors related to Control. Can. J. Bot., 1952, **30,** 537–48.
13. J. L. Bolton. Progress in Breeding for Resistance to Winter Crown Rot. Report 12th Alf. Imp. Conf., 1950, 62–64.
14. E. J. Hawn and M. W. Cormack. Crown Bud Rot of Alfalfa. Phytopath., 1952, **42,** 510–11.
15. M. W. Cormack. Studies on *Ascochyta imperfecta*, a Seed- and Soil-borne Parasite of Alfalfa. Phytopath., 1945, **35,** 838–55.

16. W. E. Bowser and A. G. McCalla. Cropping for Profit and Permanency. Univ. Alberta, Dept. Ext., 1950, Bull. No. 44, 64 pp.
17. J. Mitchell *et al.* Soil Survey of Southern Saskatchewan. Univ. Saskatchewan, Coll. Agric., Soil Survey Report, 1944, No. 12, 259 pp.
18. J. L. Bolton. The Forage Resources of Western Canada. Proc. 17th Ann. Meeting, Can. Soc. Animal Prod. (Mimeographed), 1948, 34–37.
19. R. A. Oakley and S. Garver. Two Types of Proliferation in Alfalfa. U.S.D.A. Circ., 1913, No. 115, 13 pp.
20. J. T. Jenkin. The Method and Technique of Selection, Breeding and Strain Building in Grasses. Imp. Bur. Pl. Gen., Herb. Pl. Bull., 1931, No. 3, 5–34.
21. H. M. Tysdal *et al.* Alfalfa Breeding. Coll. Agric., Univ. of Nebraska, Agric. Expt. Stat., 1942, Res. Bull., No. 124, 46 pp.
22. —— and B. H. Crandall. The Polycross Progeny Performance as an Index of the Combining Ability of Alfalfa Clones. J. Am. Soc. Agron., 1948, **40,** 293–406.
23. Utah Agric. Expt. Station and U.S.D.A. Growing Alfalfa for Seed in Utah. Utah Agric. Expt. Stat. and U.S.D.A., 1950, Circ. No. 125, 72 pp.
24. R. P. Knowles. The Role of Insects, Weather Conditions, and Plant Character in Seed Setting of Alfalfa. Sci. Agric., 1943, **24,** 29–50.
25. J. D. Aughtry, Jr. Effect of Genetic Factors in *Medicago* on Symbiosis with *Rhizobium*. Cornell Univ. Agric. Expt. Stat., 1948, Memoir, No. 280, 18 pp.
26. W. J. White. An Improved Method of Rooting Alfalfa Cuttings. Sci. Agric., 1946, **26,** 194–7.
27. H. M. Tysdal and J. R. Garl. A New Method for Alfalfa Emasculation. J. Am. Soc. Agron., 1940, **32,** 405–7.
28. R. G. Savage. Moisture Determinations in the Comparative Testing of Forage Crops for Hay Yield. Sci. Agric., 1949, **29,** 305–29.
29. J. R. Fryer. The Maternal-line selection Method of Breeding for Increased Seed-setting in Alfalfa. Ibid., 1939, **20,** 131–9.
30. J. M. Armstrong. Self-sterility Studies in Alfalfa. Ibid., 1952, **32,** 153–62.

(*Received April 28, 1953*)

# THE EFFECT OF A SUB-CLINICAL WORM-BURDEN ON THE LIVEWEIGHT GAIN OF LAMBS

C. R. W. SPEDDING

(*Grassland Research Station, Stratford on Avon*)

THE presence of parasitic nematodes in the alimentary tract of sheep results in considerable economic loss, and it is becoming increasingly appreciated that this occurs even though it may not result in the actual death of the infested animal [1, 2, 3]. Gordon [4] summarized the present attitude that the sub-clinical effects 'on appetite, wool-production and digestibility of protein and minerals indicate that the disease may cause considerable economic loss before it is detected, and indeed it may never reach a clinical stage which leads to a definite diagnosis'. This emphasis on the sub-clinical level of infestation becomes increasingly important as anthelmintics become more efficient and their use more widespread. It is, therefore, important to ascertain the effect of sub-clinical parasitism on animal health and production, and to determine the minimum size of worm-burden necessary to produce harmful effects. Of the latter, probably the most outstanding is connected with animal liveweight gain, which is of concern not only to the sheep farmer but also in connexion with work on the evaluation of pasture production in terms of stock output. Sears [5] and Brynmor Thomas *et al.* [6] consider that the productivity and growth-rate of the grazing animal remain the best criteria of feed-quality in pastures. In this work relatively small effects are of significance when assessing the factors affecting liveweight production from grassland.

In a previous study [7] the chief difficulty arising in an investigation of the effect of size of worm-burden on liveweight gain of sheep was that of measuring differences in worm-burden. The egg-counting technique suffers from numerous disadvantages [8], and it was concluded that the use of worm-free controls would be advantageous. In the present experiment such a procedure was accordingly adopted.

*Method.*—Six pairs of twin lambs, Suffolk × Halfbred wethers, were raised worm-free up to the age of 4 months. This was done by bringing both the ewes and lambs into indoor pens immediately after lambing and cleaning out the pens every 2 days.

The ewes received a ration of crushed oats containing powdered phenothiazine, frozen grass, and hay. The lambs were weaned at 4 months and were separated into two groups of six, being numbered 3–14, consecutive numbers indicating twins. The two groups consisted of all the odd numbers (Group O) and all the even numbers (Group E), so that each group contained one member of each twin pair. The lambs were weighed regularly from birth and both groups were known to have gained in weight at approximately equal rates. Group O was, however, slightly heavier in total weight than Group E. On August 1, 1952, when the lambs were approximately 4 months old, those of Group O were

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953.]

artificially dosed with infective larvae of *Trichostrongylus axei*, at three levels of infection with two animals at each level.

TABLE 1. *Details of Dosing with Trichostrongylus axei*

| *Level of infection* | *Lambs dosed* | *Number of larvae administered* | |
|---|---|---|---|
| | | *Daily* | *Total* |
| 1 | Nos. 3 and 5 | 4,000 | 48,200 |
| 2 | Nos. 7 and 9 | 6,000 | 73,000 |
| 3 | Nos. 11 and 13 | 8,000 | 115,800 |

The liveweight gains of the two groups were followed for 10 weeks after this dosing, the lambs being weighed daily on four successive days at the beginning and end of the experiment. The differences between the means of these weighings were taken as the liveweight gain. In addition, all the animals were weighed several times in the course of a week to allow the liveweight changes to be followed throughout the duration of the experiment. The two groups were kept in adjoining pens and offered the same quantity and quality of feed in the form of frozen grass and hay. The latter was fed *ad lib.* to both groups.

*Results.*—The liveweight gain for each lamb from the time of dosing with infective larvae to the completion of the experimental period is given in Table 2.

TABLE 2. *Liveweight Gains (in lb.) of Lambs of Groups O and E From August 1 to October 12, 1952*

| | *Lamb nos.* | *Liveweight gain* | *Mean liveweight gain at each level of infection* | *Average liveweight gain of groups* |
|---|---|---|---|---|
| Group O | 3 | 14·0 | 17·8 | 10·9 |
| | 5 | 21·6 | | |
| | 7 | 0·2 | 7·1 | |
| | 9 | 13·9 | | |
| | 11 | 9·0 | 7·9 | |
| | 13 | 6·7 | | |
| Group E | 4 | 18·9 | 21·9 | 22·6 |
| | 6 | 24·8 | | |
| | 8 | 19·8 | 19·7 | |
| | 10 | 19·5 | | |
| | 12 | 22·5 | 26·3 | |
| | 14 | 30·1 | | |

It will be seen that each control lamb gained more weight than its infected twin and that the depression in the rate of gain was broadly correlated with the dosage of larvae given, lamb No. 7 being the one exception. This lamb appeared to be extremely susceptible to the infestation established and rapidly lost weight after the first appearance of eggs in its faeces. It was found necessary to arrest this trend by administering

10 gm. of phenothiazine on September 24, after which the lamb again gained weight. At the end of the experiment, however, its net gain in weight was still disproportionately low. The liveweight of this animal and of its twin (lamb No. 8) is shown graphically in Fig. 1 to illustrate the extreme effect of the worm-burden on such a susceptible animal.

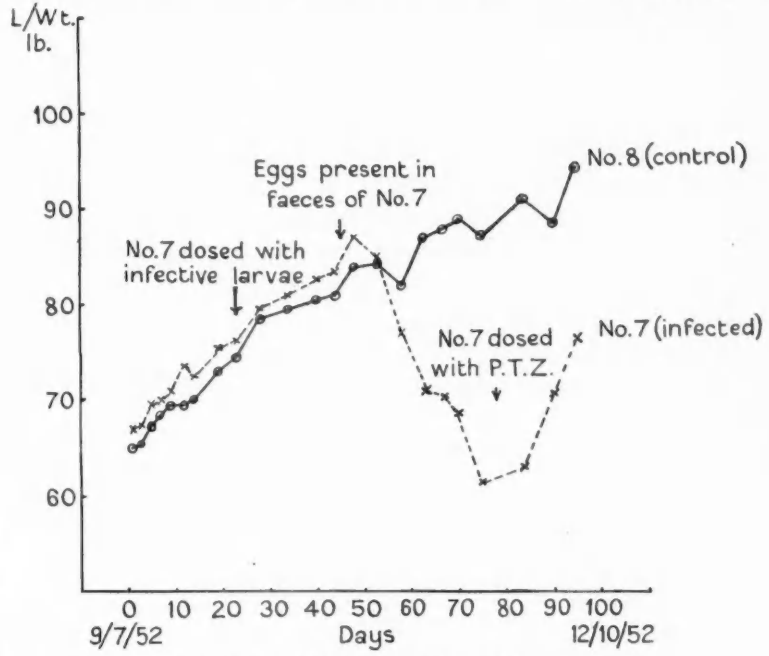



FIG. 1. Liveweight changes of Lamb Nos. 7 and 8

Up to September 24, lamb No. 7 clearly suffered a clinical level of infestation and considerably reduced the group average in consequence. The other five lambs of Group O all gained weight during the experiment and appeared to be suffering only from sub-clinical infestations, as indicated by their egg-counts given in Table 3.

TABLE 3. *Egg-count Data for Group O Lambs*
(Average of 14 counts)

| *Lamb nos.* | *Av. eggs per gm.* | | |
|---|---|---|---|
| | *T. axei* | *S. papillosus* | *Nematodirus spp.* |
| 3 | 28 | 23 | 1 |
| 5 | 24 | 48 | 2 |
| 7 | 12 | 14 | 1 |
| 9 | 29 | 28 | 1 |
| 11 | 80 | 136 | 1 |
| 13 | 23 | 53 | 1 |

The average liveweight gain of each group is shown in Fig. 2.

As there were two lambs at each level of dosing, their mean liveweight gain may be compared with that of their twins. These means and the average liveweight gain of the groups are also shown in Table 2.

The mean liveweight gain for lamb Nos. 7 and 9 (at the intermediate level of dosing) was less than that of lamb Nos. 11 and 13 (at the highest level of dosing) on account of the extreme reaction of lamb No. 7 in the former pair. This illustrates the advantage that the use of twins appears to confer on liveweight studies, for lamb Nos. 12 and 14 gained considerably more weight than lamb Nos. 8 and 10, so that the gain of lamb Nos. 7 and 9 relative to their control twins still compared favourably with that of lamb Nos. 11 and 13 relative to their control twins.

In this experiment the liveweight differences were considerable. Nevertheless, ignoring the twin relationship, lamb No. 5 might be compared favourably with any of the six control lambs. In three of these comparisons the infected lamb (No. 5) would appear to have been unaffected by the presence of parasites, as its liveweight gain was higher than that of the undosed control lambs (Nos. 4, 8, and 10). Comparing this animal with its twin (No. 6) a difference is evident. Statistically, the advantage of using twins was negligible and reduced the number of degrees of freedom, thus limiting the statistical treatment of the results.

TABLE 4. *Mean Differences between Liveweight Gain in lb. of Infected Lambs at each Dose-level and their Control Twins from Aug. 1 to Oct. 12, 1952*

| *Dose level* | *Liveweight difference* | *Av. difference in liveweight gain between groups* |
|---|---|---|
| 1 | 4·1 | |
| 2 | 12·6 | 11·7 |
| 3 | 18·4 | |

In comparing not only the actual liveweight gain of the lambs but also the differences between the mean liveweight gain of the two lambs at each level of infection and that of their worm-free twins (Table 4), it is seen that although lamb Nos. 7 and 9 gained only 7·1 lb. as against 7·9 lb. for lamb Nos. 11 and 13, the difference between this and the liveweight gain of their controls (Nos. 8 and 10) was 12·6 lb., as against a difference of 18·4 lb. between lamb Nos. 11 and 13 and their twins (Nos. 12 and 14). In this way the depression of liveweight gain may be measured, using the two equivalent twins as an index of the rate of gain of normal worm-free animals. This comparison, in spite of the extreme effect of lamb No. 7, would appear to indicate that the amount by which rate of liveweight gain was depressed was proportional to the dosage of larvae given. When lamb Nos. 7 and 8 are not taken into account the difference between the liveweight gain of Nos. 9 and 10, at the medium dose level, would give a gain difference of 5·6 lb. between the infected and non-infected animals.

Consideration of the group-liveweight curves shown in Fig. 2 gives some indication that the lambs in Group O received a check in their rate of liveweight gain during the period between infection and the first appearance of eggs in the faeces, when the worms would be present in the larval stages. This check was first detectable approximately 1 week after dosing and continued to operate for a period of 2 weeks. A period

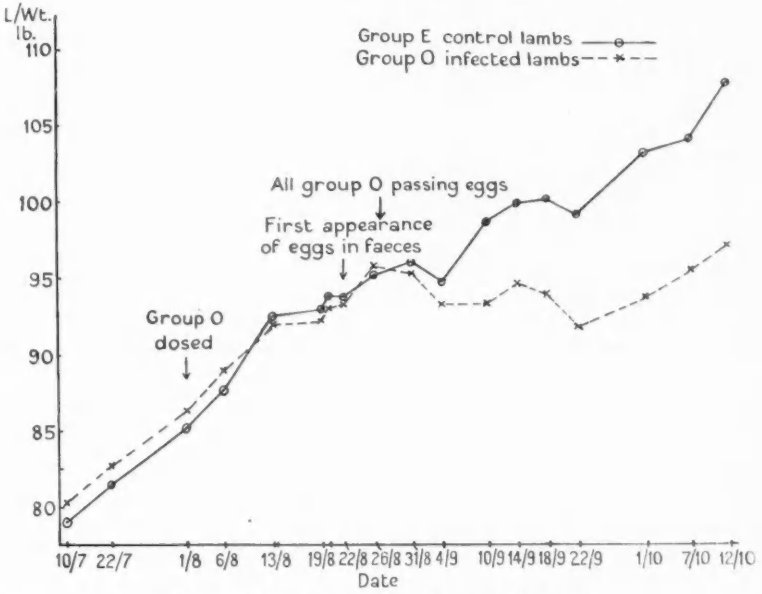



FIG. 2. Liveweight gains of Groups O and E

of recovery then supervened for nearly a week. Should this check be due to larval damage it may in part have been due to a depression of appetite with a consequent reduction in the weight of gut-contents, whilst the recovery might then represent a regain of appetite. The differences during the period were not significant, but there were indications of a difference at the highest dose-level.

Three other effects were apparent during the experiment and were concerned with (*a*) consistency of the faeces, (*b*) feed-intake, and (*c*) egg-counts.

(*a*) The faeces of the infected animals were frequently very loose and scouring occurred irregularly, particularly in lamb Nos. 5, 7, and 9. At no time were the faeces of lambs in Group E loose nor was there scouring in this latter group.

(*b*) The amount of food consumed was not measured, but an indication could be obtained by observing the amount left uneaten. On September 20 it was first possible to be quite certain that the infected animals were eating less than the controls. This difference in appetite

was maintained and grew more marked as the experiment proceeded. It was one factor in a definite trend towards lessened activity in Group O. The control animals were noticeably more lively, particularly towards the end of the experiment.

(*c*) *Egg-count data.* The infective larvae supplied were slightly contaminated by *Strongyloides papillosus* and *Nematodirus* spp. This was considered of no disadvantage, since they could be distinguished in the egg-counts, and were typical of the normally infected lamb at pasture. The control lambs occasionally produced a few eggs of these two species, but never in significant numbers. The average egg-counts are shown in Table 3. None of the counts of *Nematodirus* eggs was high enough (maximum count = 11 e.p.g.) to be regarded as indicating a significant number of worms.

Both the counts of *Strongyloides papillosus* eggs and those of *Trichostrongylus axei* were surprisingly low, considering the numbers of larvae administered, and it was possible only to distinguish a slightly higher egg output at the highest level of infection. Although the number of larvae administered does not necessarily indicate the number of adult worms established, it seems unlikely that the egg-counts represent it more accurately. This is particularly so in view of the liveweight data, and the fact that the egg-counts were on an e.p.g. basis. The latter was unavoidable, as the animals were neither bagged nor segregated.

*Discussion.*—The levels of infection administered in this experiment produced a depression in liveweight gain of infected animals, and this was in proportion to the size of dose. The consequent lowering of liveweight was sufficient to be of practical importance. It is relevant to note that the animals were not protected by any acquired resistance, as they were all raised worm-free. On the other hand, they were protected from reinfection, were well fed and thrifty when dosed. The difference in liveweight gain between the two groups was significant at the 5 per cent. level, with 95 per cent. confidence limits of 2·80 and 20·60. It was not possible to compare statistically the three levels of infection, due to the small number of animals available for dosing at each level.

The most important feature of the egg-count data was the relatively low level of the counts, even at the maximum dosage level. Infestations indicated by such counts are certainly to be regarded as sub-clinical. Taken in conjunction with the fact that the average liveweight of lambs in Group O was 97·3 lb. at the end of the experiment, the level of infestation appeared to be of an order similar to that carried by normal pasture-raised lambs.

The lowering of potential liveweight gain by these lambs may not have been greater than occurs normally in any farm flock. The loss, however, was considerable, particularly as it took place over an experimental period of only 10 weeks, and, as may be seen from Fig. 2, occurred almost entirely during the last 7 weeks of this period. A few weeks after the experiment was concluded the egg-counts rose to much higher levels (a maximum of 800 e.p.g. for *T. axei*, and about 2,000 e.p.g. for *S. papillosus*). The *S. papillosus* counts exhibited a much better correlation with dose-levels than did those of *T. axei*.

The animals were kept under observation for some months after the experiment. At the end of December 1952, the difference in average liveweight gain was still appreciable. The lambs in Group E were on the average 16 lb. per head heavier than those of Group O. Perhaps the most interesting feature of the experiment is that even at the lowest level of infection there was a depression of liveweight gain. This was, however, relatively small, and it appears likely that, for the species of nematode involved, this level comes near to that at which the effects are difficult to measure. In this experiment this level was probably more accurately defined by taking into consideration the number of larvae administered (48,200) and the subsequent level of egg-counts, approximately 500 *T. axei* e.p.g. (500,000 eggs-per-day) and 300 *S. papillosus* e.p.g. (300,000 e.p.d.).

*Summary.*—A group of six worm-free lambs gained an average of 22·6 lb. per head during a 10-week experiment, but their six twins, infected with *Trichostrongylus axei* and *Strongyloides papillosus*, gained only 10·9 lb. per head.

The weight-gains of the infected lambs appeared to be directly related to the levels of infection to which they were subjected. It is concluded that, even at sub-clinical levels, the economic loss was considerable and of real practical importance in relation to the production of mutton and lamb.

*Acknowledgements.*—The author is indebted to Dr. William Davies for facilities to carry out the work; to Mr. G. Pearson Hughes for his advice and interest; to Mr. C. D. Kemp for the statistical treatment of the results; and to Mr. T. H. Brown for technical assistance. The author particularly wishes to express his gratitude to Mr. T. E. Gibson, Ministry of Agriculture, Veterinary Laboratory, Weybridge, for the benefit of his views in discussion, and for the infective larvae which he kindly offered to culture and supply.

## REFERENCES

1. H. G. Bowes, A Few Notes on some of the Common Sheep Diseases met with in Yorkshire. Vet. J., 1932, **88**, 209.
2. T. W. M. Cameron, The Internal Parasites of Sheep: A Survey. Ibid. 140–8.
3. H. W. Tomlinson, Management in relation to Internal Parasites of Sheep. Agric. Progr., 1938, **15** (2), 86.
4. H. McL. Gordon, Some Aspects of Parasitic Gastro-Enteritis of Sheep. Aust. Vet. J., 1950, **26** (2).
5. P. D. Sears, The Technique of Pasture Management. N.Z. J. Sci. & Tech., Sect. A, 1948, **30**, No. 4.
6. Brynmor Thomas, A. Thompson, V. A. Oyenuga, and R. H. Armstrong, The Ash Constituents of some Herbage Plants at Different Stages of Maturity. Empire J. Expt. Agric., 1952, **20**, 10–22.
7. C. R. W. Spedding, The Effect of a Sub-clinical Worm-burden on the Liveweight Gain of Sheep at Pasture. Ibid. 209–19.
8. —— The Value of the Faecal Egg-count in Sheep. Vet. Rec., 1952, **64**, No. 50, 813–15.

(*Received March 24, 1953*)

# A SURVEY OF THE VALUE OF FERTILIZERS TO THE FOOD-FARMING AREAS OF THE GOLD COAST

## PART II. THE GRANITIC SOILS OF THE FAR NORTH

P. H. NYE

In Part 1 of this series (this *Journal* 1953, **21**, 176) an account was given of the methods used in a survey to determine the responses to be expected from sulphate of ammonia and superphosphate under native farming conditions in some heavily farmed areas. In this Part the results of the survey in the densely populated granitic region in the north of the country are described. The region comprises four areas, Bawku, Zuarungu, Navrongo and Lawra, totalling 4,370 sq. miles, whose results may be considered together, for they have similar soils, climate, and agriculture. Between them they cover the whole of the densely farmed areas of the far north, with the exception that a small but important belt of very different soils developed over greenstone has been separated as the Nangodi area, and will be considered at the end of this Part. A brief description of the significant features of each area follows.

### *Area Boundaries*

Bawku. French Boundary, latitude 10°45′ N., Red Volta River (excluding greenstone soils).

Zuarungu. French boundary, Red Volta River, latitude 10°40′ N., River Atankwidi (excluding greenstone soils).

Navrongo. French boundary, River Atankwidi, latitude 10°40′ N., longitude 1°20′ W.

Lawra. French boundary, longitude 2°20′ W., latitude 10° N.

### *Soils*

The soils are developed mainly from granite, granodiorite, or granitic gneiss and schists. The country is usually gently undulating with occasional rocky outcrops; dry-farming is pursued on all parts of the slopes except on severely eroded upper slopes underlain by rock or iron pan, and on lower slopes and valleys very poorly drained. On each type of rock there is a catenary sequence of soils. On the upper slopes there is usually about 6–12 in. of reddish, yellowish, or greyish-brown loose, coarse sandy loam, or loamy coarse sand with single-grain structure, merging into red, yellow, or brown, usually mottled, moderately compact, structureless sandy clay, which merges into decomposing rock at some 5 to 10 ft. depth. There is usually an accumulation of quartz and ferruginous gravel, sometimes forming a hard pan, about 2 ft. thick, within 18 in. of the surface; and on eroded sites this may be exposed by cultivation. On the middle slopes there is a greater thickness of loose sandy loam overlying the more compact subsoil and the gravel is found at greater depth; whilst on the lower slopes there is usually a considerable depth of colluvial coarse sand or coarse sandy loam overlying the sandy

[Empire Journ. of Exper. Agric., Vol. 21, No. 84 1953.]

clay, and colours tend to be more greyish due to the poorer drainage. The areas also contain subsidiary fine sandy soils developed over Birrimian phyllites, but these are little farmed and of scant importance except in the Lawra area, though even there Hinds [1] considers that most of the farming on the part marked as Birrimian on the geological map is actually taking place on small granitic intrusions through the Birrimian.

The only soils excluded from selection as experimental sites were those within 50 yds. of compounds, which are usually of exceptionally high fertility, and river levees which often carry very good crops of guinea corn.

*Climate*

The average annual rainfall ranges from 49 in. in Lawra to 39 in. in Bawku. The rainy season lasts from about mid-April to mid-October with a maximum fall in August and September. The dry season is

TABLE 1. *Rainfall Data for Selected Stations in the Northern Granitic Area*

| | *LAWRA* | | | | *NAVRONGO* | | | |
|---|---|---|---|---|---|---|---|---|
| | *Year* 1950 | | *Average* | | *Year* 1950 | | *Average* | |
| *Month* | *in.* | *Rain days* | *in.* | *Rain days* | *in.* | *Rain days* | *in.* | *Rain days* |
| January | 0·28 | 2 | 0·08 | 1 | 0·00 | 0 | 0·02 | 1 |
| February | 0·69 | 1 | 0·15 | 1 | 0·00 | 0 | 0·19 | 1 |
| March | 0·84 | 1 | 1·03 | 2 | 0·00 | 0 | 0·58 | 2 |
| April | 1·97 | 4 | 2·66 | 4 | 0·81 | 3 | 2·21 | 4 |
| May | 5·15 | 8 | 5·23 | 7 | 4·59 | 8 | 4·36 | 7 |
| June | 5·98 | 13 | 6·71 | 5 | 6·17 | 12 | 5·81 | 9 |
| July | 5·68 | 7 | 8·03 | 10 | 9·55 | 16 | 7·27 | 10 |
| August | 11·37 | 12 | 11·10 | 14 | 11·64 | 15 | 10·69 | 14 |
| September | 9·39 | 18 | 9·61 | 14 | 13·22 | 18 | 8·76 | 14 |
| October | 1·47 | 5 | 3·62 | 7 | 1·73 | 5 | 2·63 | 7 |
| November | 0·19 | 1 | 0·65 | 1 | 0·47 | 1 | 0·21 | 1 |
| December | 0·00 | 0 | 0·09 | 1 | 0·00 | 0 | 0·07 | 1 |
| *Annual Total* | 43·01 | 72 | 48·96 (24 years) | 67 | 48·18 | 78 | 42·80 (24 years) | 71 |
| | *ZUARUNGU* | | | | *BAWKU* | | | |
| January | 0·00 | 0 | 0·07 | 1 | 0·00 | 0 | 0·01 | 1 |
| February | 1·10 | 1 | 0·40 | 1 | 0·64 | 1 | 0·15 | 1 |
| March | 0·00 | 0 | 0·67 | 2 | 0·00 | 0 | 0·73 | 1 |
| April | 0·10 | 1 | 2·05 | 4 | 0·22 | 2 | 1·78 | 3 |
| May | 2·03 | 7 | 4·08 | 8 | 4·17 | 5 | 3·36 | 6 |
| June | 5·51 | 9 | 6·09 | 9 | 4·68 | 6 | 5·03 | 9 |
| July | 7·61 | 13 | 6·43 | 10 | 5·45 | 7 | 6·52 | 11 |
| August | 9·46 | 16 | 9·60 | 13 | 9·96 | 9 | 10·06 | 15 |
| September | 8·11 | 20 | 8·36 | 14 | 8·10 | 14 | 8·34 | 13 |
| October | 3·29 | 7 | 2·29 | 7 | 2·65 | 5 | 2·35 | 5 |
| November | 0·00 | 0 | 0·51 | 1 | 0·08 | 1 | 0·36 | 1 |
| December | 0·00 | 0 | 0·04 | 1 | 0·00 | 0 | 0·03 | 1 |
| *Annual Total* | 37·21 | 74 | 40·59 (32 years) | 71 | 35·95 | 50 | 38·72 (23 years) | 67 |

severe, with low humidity. The rainfall in 1950 is compared with the average in Table 1. The annual average temperature is 82° F.

*Agriculture*

The farming in North Mamprussi—the Bawku, Zuarungu, and Navrongo areas—has been well described by Lynn [2], and in the Lawra area by Hinds [1]. Throughout this northern region, with the exception of part of the Lawra area farmed by Dagartis, a settled system of agriculture is practised. The farmers live on their land in isolated compounds. The land immediately surrounding the dwelling is known as the compound farm, and is cropped continuously, the non-compound land beyond being occasionally fallowed; an average size for both a compound and a non-compound farm is 5 acres, though there are wide variations. Patches of crops range from ¼ acre to some 4 acres on bigger farms.

On the compound farms cereals are usually grown continuously with an occasional break for groundnuts; the cereals are guinea corn (*Sorghum* sp.) or late millet (*Pennisetum* sp.), sometimes mixed, and both are nearly always interplanted with early millet (*Pennisetum* sp.). All the cereals are planted with the early rains in April or May. Early millet grows and matures rapidly and is harvested before the heavy August rains; the late millet and guinea corn grow more rapidly during August and September and are not harvested until November. On the non-compound farms, which receive less attention, guinea corn or late millet is usually planted without early millet owing to lack of time; groundnuts are also grown, either in a rotation with cereals or continuously on the same piece of ground.

Any manure and household refuse is spread on the compound farm and rarely on the non-compound farm. An average application is 2 tons per acre. The residual effect of the manure is known to be appreciable for at least 2 years after application, and fields on the compound farm are rarely manured more than once in 2 or 3 years. For these reasons any sites that have received manure in the last 3 years are grouped as manured sites in these experiments. Manure is usually dung, though increasing numbers of farmers are using straw to make f.y.m.

The land of the non-compound farm is periodically left under a natural grass fallow, but in most instances it was at least 3 years since the last fallow period, and the land is more often under a crop than fallow.

The Lawra area is divided between the Lobi and Dagarti farmers. The Lobis live in scattered compounds and use the land in a similar way to the North Mamprussi tribes. On the other hand the Dagartis live in villages and nearly all their farms are non-compound, with approximately 7 years fallow to 3 years cropping; consequently most of the Lawra sites are non-compound. Early millet is not planted by either tribe.

*Experimental Results*

The most important results in these areas are summarized in Table 2, which shows the mean responses over the whole of the far north for each of the main crops or mixed crops. It is clear from the figures that all the crops show high responses to superphosphate. The cereals show

considerable responses to sulphate of ammonia, though not to the same extent as to superphosphate. The responses and mean yields fall into a number of natural ways of grouping under which they will be discussed in turn.

TABLE 2. *Areas of the Far North. Responses to Single (60 lb. per acre) and Double (120 lb. per acre) Dressings of Sulphate of Ammonia and Superphosphate, and their Linear Interactions*

$N_1$, $P_1$, are responses to single dressings; $N_2$, $P_2$ are responses to double dressings. (lb. per acre of dry grain or kernels)

| *Crop* | *No. of sites* | *Responses* | | | | | | *Lin. Int.* | *Mean Yield* | *S.E.* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $N_1$ | $N_2$ | S.E. ($N_2$) | $P_1$ | $P_2$ | S.E. ($P_2$) | $N_2 \times P_2$ | | |
| E. millet and G. corn | 55 | 87 | 110 | .. | 120 | 186 | .. | −8 | 587 | .. |
| | | 71 | 132 | .. | 95 | 172 | .. | 34 | 423 | .. |
| | | 158 | 242 | 35 | 215 | 358 | 42 | 26 | 1,010 | 73 |
| E. millet and L. millet | 47 | 67 | 53 | .. | 117 | 156 | .. | −6 | 476 | .. |
| | | 45 | 67 | .. | 52 | 102 | .. | 2 | 385 | .. |
| | | 112 | 120 | 28 | 169 | 258 | 34 | −4 | 861 | 82 |
| G. corn alone | 23 | 20 | 84 | 32 | 128 | 197 | 40 | 108 | 354 | 61 |
| L. millet alone | 25 | 67 | 74 | 23 | 96 | 147 | 32 | 32 | 346 | 53 |
| Average All cereals | 150 | 108 | 151 | .. | 168 | 267 | .. | 30 | 752 | .. |
| Groundnuts | 76 | Not applied | | | 191 | 311 | 29 | .. | 682 | 33 |

*The Different Crops*

*Mean yields.*—The striking difference in mean yields between the mixed and single cereals will be noticed. The yields of guinea corn and late millet are slightly greater when mixed with early millet than when they are growing alone. The reasons are, first, that the mixed cereals are as a rule grown on the more fertile and better tended compound land, and include a much higher proportion of manured sites; and second, that the early millet matures in late July while the late cereals are only about 2 ft. high, and it is off the ground when they are making most of their growth, so that competition is not so severe as might be expected.

*Responses.*—The responses of the individual cereals, ignoring mixed cropping, are:

| | $N_1$ | $N_2$ | $P_1$ (*lb. per acre*) | $P_2$ | $N_2 \times P_2$ | *Mean* |
|---|---|---|---|---|---|---|
| Early millet | 78 | 84 | 119 | 172 | −7 | 535 |
| Guinea corn | 56 | 118 | 105 | 179 | 56 | 403 |
| Late millet | 53 | 69 | 67 | 118 | 12 | 371 |

*Main effects.* The responses to sulphate of ammonia are about the same on the three cereals within the limits of error. The responses to superphosphate are almost the same on early millet and guinea corn, but are consistently lower on late millet. The greater responsiveness of guinea corn than late millet seems to be recognized by farmers in the Lawra area, who give nearly all their manure to the guinea corn. In North Mamprussi the manure is divided about equally between mixed early millet and guinea corn and mixed early and late millet.

Table 2 shows that the responses of guinea corn and late millet to superphosphate are only slightly lower when mixed with early millet than in pure stand, and the increased yields of early millet more than compensate for the reduction; consequently any fertilizer should be applied to mixed cereals rather than single cereals.

*Rate of application.* The variation of response with rate of application is not linear for either of the fertilizers. From the averaged figures of the responses of all the cereals (Table 2), it may be seen that the second increment of sulphate of ammonia gives only two-fifths the return of the first, and the second increment of superphosphate gives three-fifths of the return of the first. On groundnuts the second increment of superphosphate also gives about three-fifths the return of the first. Within the limits of error this falling off in response is consistent for all crops.

*Linear Interactions.*—The only significant interaction between nitrogen and phosphorus was obtained on sites growing guinea corn alone. For the rest of the cereals and for guinea corn growing with early millet the interactions were small.

### *Effects of Organic Manuring*

*Mean yield.*—The difference between the mean yield on manured and unmanured sites, i.e. the effect of organic manuring, is shown in the first part of Table 3.

The effect of organic manure is very clear, the average yield of each of the crops on manured sites being more than 50 per cent. greater than on unmanured sites. On the mixed cereals the effect of the organic manure is almost equally divided between the early and the late crops. It has been pointed out that any site which has received manure in the past 3 years was classified as a manured site. In most instances a 'manured site' will have been manured at fairly regular intervals in the past, and an 'unmanured site' will not have received any manure for many years, if ever. Thus the difference in yield between the manured and unmanured sites reflects a difference in the general level of fertility over years rather than a response to one application of manure.

The difference in the response to fertilizers on the manured and unmanured sites is shown in the second part of Table 3, and it will be seen that there are no consistent trends. The large differential response to the double level of nitrogen in the mixed early and late millet crop is largely due to the early millet, but the effect is absent when the early millet is grown with guinea corn. There is also an indication that late millet and guinea corn growing alone respond better to phosphorus on the manured sites, though there is no indication of such an effect on the

mixed cereals. Certainly there is no evidence in these figures to suggest that inorganic fertilizers should not be used on manured land.

TABLE 3. *Difference between Mean Yields and Responses on Manured and Unmanured Sites*

(lb. per acre)

| Crops | No. of sites* | | Diff. in mean yields (Man.-Unman. sites) | | Diff. in responses (Man.-Unman. sites) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Man. | Unman. | | S.E. | $N_1$ | $N_2$ | S.E. ($N_2$) | $P_1$ | $P_2$ | S.E. ($P_2$) |
| E. millet and G. corn | 27 | 20 | 449 | 141 | 86 | −38 | 76 | −75 | −69 | 92 |
| E. millet and L. millet | 23 | 21 | 462 | 157 | 85 | 167 | 52 | −27 | 24 | 71 |
| G. corn alone | 6 | 17 | 202 | 139 | −38 | 41 | 73 | 42 | 132 | 92 |
| L. millet alone | 5 | 19 | 208 | 133 | −40 | −15 | 57 | 170 | 112 | 80 |
| Ground-nuts (kernels) | 16 | 60 | 309 | 74 | Not applied | | | 78 | 87 | 71 |

* It was not possible to obtain information about some sites and their results are not included.

If, as is usually assumed, the clearly beneficial effect of manure was due primarily to its phosphorus-content, a reduction in the effect of phosphorus on the manured sites might be expected, similar to that obtained on trials at experimental stations in these areas [3]. The reason why there is no indication of such an effect in these results may lie in one or more of the following points: (*a*) that the manure is raising the general fertility to such an extent that the crops are able to respond better to the extra phosphorus supplied; (*b*) that the response to phosphorus is still sufficiently linear at the low rates of application of superphosphate and manure being considered. In the experimental station trials the negative dung×phosphorus interactions were obtained with applications of 2 cwt./acre of superphosphate and 4 t./acre of dung, compared with 60 or 120 lb./acre of superphosphate, and about 2 t./acre of manure applied any time in the past 3 years, in these experiments; (*c*) the errors in this series are too high for small differences in responses to be detected.

### *Variations Between Areas*

The responses and mean yields for the different areas are shown in Table 4. Area differences between early millet and guinea corn are very similar to those between early millet and late millet; hence their results have been pooled under the heading 'mixed cereals'. The same is true

for guinea corn alone and late millet alone, whose results are headed 'single cereals'.

TABLE 4. *Responses and Mean Yields in the Different Areas*

(lb. per acre)

| *Area* | *No. of sites* | *Responses* | | | | | | *Mean yield* | *S.E.* |
|---|---|---|---|---|---|---|---|---|---|
| | | $N_1$ | $N_2$ | S.E. ($N_2$) | $P_1$ | $P_2$ | S.E. ($P_2$) | | |
| | | | | *Mixed Cereals* | | | | | |
| Bawku | 41 | 60 | 97 | 26 | 80 | 185 | 40 | 977 | 87 |
| Zuarungu | 27 | 269 | 278 | 46 | 261 | 401 | 57 | 1,207 | 109 |
| Navrongo | 34 | 124 | 194 | 43 | 284 | 376 | 43 | 665 | 70 |
| Lawra | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| | | | | *Single Cereals* | | | | | |
| Bawku | .. | .. | .. | .. | .. | .. | .. | .. | .. |
| Zuarungu | 4 | (89) | (144) | 60 | (0) | (106) | 84 | (434) | 148 |
| Navrongo | 22 | 72 | 144 | 28 | 128 | 241 | 35 | 341 | 39 |
| Lawra | 22 | 23 | 50 | 30 | 107 | 141 | 35 | 390 | 73 |
| | | | | *Groundnuts (kernels)* | | | | | |
| Bawku | 22 | Not applied | | | 167 | 222 | 51 | 726 | 48 |
| Zuarungu | 17 | ,, | ,, | | 247 | 367 | 77 | 747 | 88 |
| Navrongo | 27 | ,, | ,, | | 157 | 361 | 44 | 660 | 60 |
| Lawra | 10 | ,, | ,, | | 245 | 276 | 52 | 530 | 60 |

In the Bawku area the response to both nitrogen and phosphorus on mixed cereals is less than half the response in other areas, and the response to phosphorus on groundnuts is also considerably less, which seems to indicate a higher fertility in the Bawku area. In the Zuarungu area the response to nitrogen on mixed cereals is considerably higher than in the Navrongo area, but this may be accounted for by the better season enjoyed by this area, as shown by the mean yield. There are no other striking differences between results in each area.

### *Seasonal Variation in Responses*

These results have been obtained for 1 year only, and the extent of seasonal variations in responses has to be considered. The 1950 season was considered about average if the far north is taken as a whole. In Table 5, the yields of the *untreated* plots for each area are compared with those obtained in sample surveys of farms in North Mamprussi from 1932–6 by Lynn [2], and in the Lawra area from 1941–5 by Hinds [1].

The 1950 yields of cereals are a little lower than the average, because heavy rains in the Navrongo area caused a poor setting of seed in the guinea corn and late millet. Groundnut yields were slightly above the average. There is a fairly wide spread of mean yields from area to area; and a very wide spread from site to site, the standard error of the mean yield on a single site being 41 per cent. for groundnuts, 55 per cent. for mixed cereals, and 74 per cent. for single cereals.

TABLE 5. *Comparison of 1950 Season Yields (untreated plots) with Average Annual Yields, in lb. per acre*

(The numbers of samples are given in parentheses)

| | *E. millet and G. corn* | *E. millet and L. millet* | *Guinea corn alone* | *Late millet alone* | *Groundnuts* |
|---|---|---|---|---|---|
| North Mamprussi 1932–6 (Lynn) | 741 (*c.* 250) | 759 (*c.* 250) | 355 (*c.* 160) | 240 (*c.* 130) | 444* (*c.* 70) |
| Lawra 1941–5 (Hinds) | .. | .. | 454 (744) | 362 (382) | 464* (261) |
| 1950 survey: | | | | | |
| Bawku | 869 (19) | 709 (22) | .. | .. | 596 (22) |
| Zuarungu | 765 (14) | 824 (13) | .. | 344 (4) | 543 (17) |
| Navrongo | 452 (22) | 268 (12) | 229 (8) | 135 (14) | 487 (27) |
| Lawra | .. | .. | 258 (15) | 299 (7) | 357 (10) |
| Mean (1950) | 676 (55) | 628 (47) | 248 (23) | 214 (25) | 514 (76) |

* Shelling percentage taken at 70 per cent.

The monthly rainfall and number of days rain in each area are compared with the average in Table 1. Apart from the exceptional late rains in Navrongo, the 1950 season was very near the average.

It is intended that these trials should be carried on for a number of years, and an attempt made to correlate fertilizer responses with the nature of the season. However, information that leads to practical recommendations is urgently needed now; and in view of the wide range of individual site-yields, the variation of mean yield from area to area, the closeness of the mean 1950 yields for the whole of the far north to the general annual average, and the fact that the rainfall during the season was normal, it is considered that the fertilizer responses obtained in this survey form a satisfactory basis for recommendations.

It is interesting to note that on groundnuts, the crop to which superphosphate may be most profitably applied at present, the average responses obtained from 60 lb. per acre of superphosphate—an increase of 191 lb. per acre on an untreated mean yield of 514 lb. per acre—corresponds very closely with that quoted for the sandy soils of northern Nigeria by Greenwood [4]: 200 lb. per acre on an untreated yield of 700 lb. per acre or under.

### *The Nangodi Area*

This area is underlain by greenstone rocks that are marked by a well-defined range of hills rising above the level of the granitic plain. The soils are friable red, orange, or brown clays, with residual greenstone

gravel and stones and scattered ferruginous concretions in the subsoil. The soils on the hillsides are very shallow, but are extensively cultivated, the farmers managing to preserve a little top-soil by means of small terraces constructed from stones and boulders. In the valleys are deeper colluvial soils with an excellent physical condition. These soils may be expected to fix phosphate to a much greater extent than the granitic soils.

The agriculture is very similar to that on the surrounding granitic areas.

*Experimental results.*—The results of the trials are shown in Table 6.

TABLE 6. *Greenstone Soils. Response (lb. per acre) to Sulphate of Ammonia and Superphosphate*

| *Crops* | *No. of sites* | *Responses and linear interaction* | | | | | | | *Mean* | *S.E.* |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $N_1$ | $N_2$ | S.E. ($N_2$) | $P_1$ | $P_2$ | S.E. ($P_2$) | $N_2 \times P_2$ | | |
| E. millet and G. corn. | 5 | 92 | 153 | .. | 109 | 258 | .. | 51 | 720 | .. |
| | | 82 | 160 | .. | 163 | 415 | .. | 15 | 930 | .. |
| | | 174 | 313 | 60 | 272 | 673 | 58 | 66 | 1,650 | 163 |
| E. millet and L. millet | 6 | 51 | 190 | .. | 54 | 323 | .. | 76 | 706 | .. |
| | | 26 | 85 | .. | 40 | 181 | .. | −34 | 547 | .. |
| | | 77 | 275 | 48 | 94 | 504 | 74 | 42 | 1,253 | 116 |
| Groundnuts . | 3 | Not applied | | | 119 | 221 | .. | .. | 725 | .. |

The responses of cereals to both nitrogen and phosphorus are higher than those on the granitic areas. The responses to the double dressing of superphosphate are more than twice those of the single dressing, but this may be due to random error. The responses of groundnuts are similar to those on the granite areas.

The sites are too few to justify more detailed conclusions, but it would seem that the recommendations for the other northern areas will apply equally well to this area.

### *The Cash Return from Fertilizers*

For a variety of reasons it is very difficult to estimate the value of introducing fertilizers to a region of small-subsistence farmers in terms of cash.

(*a*) Prices of farm produce vary greatly from place to place, month to month, and season to season. Prices in 1950 and 1951 have been high owing partly to greatly reduced crops of maize, which have suffered seriously from rust. It has seemed best to base conclusions on the minimum guaranteed prices to farmers in 1950, which were fixed before any shortages were expected. At the time of writing (October 1952) food supplies are once more plentiful, and prices to the farmers are between

25 and 50 per cent. above those quoted here, whilst the cost of fertilizer on the farm is about 25 per cent. greater.

(*b*) In most instances the farmer must grow enough subsistence crops, particularly cereals, for his own consumption, and the balance of his land and labour can be devoted to cash crops such as groundnuts. He may be well advised to use fertilizers liberally on his subsistence crops, beyond the rate at which they pay directly, because by having a smaller area under subsistence crops he can have a larger area under cash crops.

(*c*) The residual effects of superphosphate are considerable and probably persist for a number of years, but at present only a conservative estimate can be given, and the use made of the residual effect will depend on the cropping.

(*d*) Most farmers sow ground crops such as cowpeas (*Vigna unguiculata*) under their cereals, which yield some 50 to 100 lb. of produce and will receive the benefits of fertilizers.

(*e*) An extra yield requires extra labour in harvesting, threshing, and marketing, though the last two operations can be done during the slack time of the year. On the other hand a good crop reduces the labour of weeding.

The combination of these factors serves to raise the value of fertilizers considerably above that obtained by the simple calculations that will now be given.

*Direct Return.*—In Table 7 the first half gives the increase in yield obtained from sulphate of ammonia or superphosphate; and from it the cash return to be expected, whatever the prices of fertilizers or produce, may readily be calculated. The second half of the table gives the net cash return to be expected at 1950 prices, after the cost of fertilizer has been deducted.

TABLE 7. *Return from Fertilizers in the Far North*

| | *Increased yield from* | | | | *Net cash return per acre* | | | |
|---|---|---|---|---|---|---|---|---|
| | *Sulphate of ammonia* | | *Superphosphate 18·5 per cent.* | | *Sulphate of ammonia* | | *Superphosphate* | |
| *Rate lb. per acre* | 60 | 120 | 60 | 120 | 60 | 120 | 60 | 120 |
| Groundnuts | .. | .. | 191 | 311 | .. | .. | 51*s.* | 77*s.* |
| E. millet and G. corn | 158 | 242 | 215 | 358 | 3*s.* | .. | 16*s.* | 20*s.* |
| E. millet and L. millet | 112 | 120 | 169 | 258 | .. | .. | 9*s.* | 5*s.* |
| G. corn alone | 20 | 84 | 128 | 197 | .. | .. | 2*s.* | .. |
| L. millet alone | 67 | 74 | 96 | 147 | .. | .. | .. | .. |

The minimum value of cereals is 17*s.* per cwt. and of shelled groundnuts 40*s.* per cwt. The prices of fertilizers at a central market in the far north are taken as: sulphate of ammonia 39*s.* per cwt.; superphosphate 32*s.* per cwt.

Superphosphate shows by far the greatest cash return on groundnuts, and it will be noted that the second dressing of 60 lb. per acre increases

the profit. This is so in all but the Lawra area, and this exception is probably due to chance variation leading to too high a response to the single dressing or too low a response to the double one. On the average a third dressing of 60 lb. per acre is likely to be profitable, but may not be so for all areas. Mixed early millet and guinea corn also show a profitable return, the second increment again showing a small profit. At neither rate did the direct effect pay in the Bawku area. Mixed early millet and late millet show a small profit on the first dressing but not on the second; and on the single cereals superphosphate is not directly profitable at either level.

Sulphate of ammonia will just show a profit at the lower level on mixed early millet and guinea corn, but on other crops it does not pay.

*Residual return.*—Trials at experimental stations on these soils show that the residual effect of superphosphate in the year following the year of application is at least 50 per cent. of the direct effect. (Details of these experiments will be published shortly.) The top-soils have a pH of about 6·5 and consist mainly of quartz, kaolin, and organic matter, and they show little tendency to absorb phosphorus in unavailable forms. It is likely that the effects of superphosphate persist into the third year, but at this stage it is considered that the residual effect may be safely taken as 50 per cent. of the direct effect.

### *The Best Use of Fertilizers*

It is wise to be cautious in making recommendations to farmers on the basis of these experimental results, both because of the difficulties in estimating the true value of fertilizers (given above), and also because it is difficult to lay down general rates of application, due to the wide variation in responses from site to site. This variation is illustrated by the effect $P_2$ on groundnuts and its standard error on a single site, viz. $311 \pm 250$ lb. per acre, though admittedly the variation on a whole field would not be so great. There is also the economic consideration that the farmer's capital is very small, and he will not usually be able to afford more than a low dressing. The decision as to the best use of fertilizers on an individual farm must ultimately depend on the farmer's intimate knowledge of his land and his experience with fertilizers, his need of subsistence crops, and his supply of capital. The general conclusions which follow can, therefore, be regarded only as tentative, and they may serve as a basis for a fertilizer extension policy which must be constantly adapted to local conditions as experience grows. Questions such as the possibilities of fertilizer subsidies, and loan schemes, are beyond the scope of this paper.

For a start farmers should apply 120 lb. per acre of superphosphate on their groundnuts. This will give a direct economic response in at least four out of five fields, and if the residual effect is taken into consideration the chances of an unprofitable return are smaller. The surveys of Hinds and Lynn [1, 2] show that approximately 12 per cent. of the farmed land in the far north is devoted to groundnuts (including 4 per cent. mixed with late millet), and about 85 per cent. to cereals. The groundnuts are usually grown in rotation with several cereal crops,

though the cropping histories of the fertilizer-trial sites show some instances in which groundnuts have been grown continuously on the same land for many years; and there are many examples of continuous cropping with cereals. If the fertilizer is applied to groundnuts occurring once in a regular rotation, the residual effect will be taken on the cereals, and the fertilizer will be spread evenly over the farm in the course of a few years. If a rotation containing two successive groundnut crops were adopted, the residual effect of the fertilizer could be taken on the second groundnut crop, which would increase the immediate profit from the application; but it would be advisable to forgo this short-term advantage, since the second groundnut crop would probably have more value to the general fertility of the farm, especially the nitrogen status, inserted between a run of cereals. As the fertility of the farm increases, less land need be devoted to subsistence cereal crops and more can be given to cash crops, particularly groundnuts. This process can be accelerated if sufficient capital is available for the application of fertilizer to mixed cereal crops. The increased acreage of groundnuts will also improve the nitrogen status of the farm which it is hardly profitable to do at present with sulphate of ammonia.

In the Lawra area Hinds [1] remarks that 'early millet is never grown owing to some nebulous prejudice against it'. The reason may be that the crop gives poor yields compared with the other cereals on poor land; and when the fertility-level is raised with superphosphate the farmers may adopt it. It certainly appears beneficial to plant mixed cereals on fertile land both in the Lawra area and on the non-compound farms in other areas, if labour is available.

The use of sulphate of ammonia now is not justified as a general rule. If cereal prices rise, 60 lb. per acre applied to early millet and guinea corn may be profitable.

The introduction of superphosphate will bring great benefits to the impoverished subsistence farmers of the far north. There are about 47,000 acres under groundnuts every year in this region. If superphosphate at the rate of 120 lb. per acre is spread on this area each year, and the residual effect taken on mixed cereals, the increased output per annum is estimated at 6,500 tons of shelled groundnuts and 3,760 tons of grain, representing a net cash return of £180,950 on groundnuts and £64,000 on grain. If, as the general fertility of the farm rises, more groundnuts are grown, the return will increase.

*Summary*

The average responses of the main crops of the region to superphosphate and sulphate of ammonia have been determined by means of large numbers of trials on cultivators' farms. It has been shown that 120 lb. per acre of superphosphate can increase the present yields of groundnuts by 61 per cent., and the present yields of cereals by 52 per cent.; 120 lb. per acre of sulphate of ammonia will increase the present yields of cereals by 29 per cent. Nearly two-thirds of these responses can be obtained by using only 60 lb. per acre of fertilizer.

The average yield on land which occasionally received kraal manure

was more than 50 per cent. greater than on unmanured land, but there was little difference in the response to fertilizers on the two types. It is therefore clear that the productivity of this impoverished region could be increased by at least 75 per cent. with very moderate amounts of inorganic fertilizers, and by over 100 per cent. if more attention is paid to organic manuring as well.

The behaviour of the individual cereals, the variation in response between the four areas of the region and the seasonal variation in response have been examined; suggestions have been made about the best way of using fertilizers, and their economic value to the region has been estimated.

## REFERENCES

1. J. HINDS, Agricultural Survey of the Lawra District. Unpublished report to the Director of Agriculture, Gold Coast, 1946.
2. C. W. LYNN, Agriculture in North Mamprussi. Bull. No. 34, Dept. of Agriculture, Gold Coast, 1937.
3. P. H. NYE, Empire J. Expt. Agric., 1952, **20**, 47.
4. M. GREENWOOD, ibid., 1951, **19**, 225.

(*Received December 30, 1952*)

# THE RESPONSE OF PIGS TO DIETARY PROCAINE PENICILLIN

K. L. ROBINSON, W. E. COEY, AND G. S. BURNETT[1]

THE effect of antibiotics in enhancing the rate of live-weight gain and the efficiency of food utilization of weanling pigs has been widely demonstrated in the U.S.A., usually, but by no means exclusively, with diets based on mixtures of soyabean meal and maize meal. In these experiments the animals have generally been self-fed in drylot and thus largely unrestricted in their consumption of food and water. This contrasts with the customary procedure in the United Kingdom where experimental diets are more often given as a wet slop, and on a conventionally restricted scale of feeding. Some investigators [1, 2] have suggested that the effect of antibiotics is to a considerable extent due to an enhancement of appetite, and the present authors have pointed out [3, 4] that an optimum response may thus not be obtained when restricted feeding is practised.

Individual assessments of the appetite of fattening pigs by means of their unrestricted food-intake present considerable practical difficulties, unless small individual pens with separate dry-meal feeders are available. If, however, it can be assumed that increased appetite is accompanied by a more rapid consumption of food then an alternative procedure could be adopted by observing the time taken to consume a given quantity of meal. The present paper records some measurements of appetite obtained by this method with various diets, together with the results of some feeding trials in which food consumption was unrestricted and in which an antibiotic was fed.

## *Experimental Details and Results*

*Measurement of appetite.*—It was observed during certain feeding trials already published [3, 4], that weanling pigs receiving white fish-meal diets or all-vegetable protein diets consumed their allotted amount of meal more rapidly when the food also contained procaine penicillin. It was assumed that this was due to a stimulation of appetite produced by the antibiotic, but since the animals were being fed according to a scale based on live-weight any effect of the treatment in promoting a greater appetite could not result in an immediate increase of food-intake. Accurate measurements were, therefore, obtained of the time taken by the individual pigs in one of the experiments [4] to consume their rations; these records were made during three successive evening feeds.

The experiment was designed as a randomized block trial of 6 treatments and 5 replications, with recently weaned pigs averaging 40 lb. live-weight at the outset. Treatments 1 and 2 received a basal all-vegetable diet consisting of, as percentages, barley meal 37, bran 20, maize meal 20, earthnut meal 20, and dried-grass meal 3, with a mineral supplement; in the remaining treatments the earthnut meal was reduced

[1] The Queen's University, Belfast, the Ministry of Agriculture (N.I.), and the Agricultural Research Institute (N.I.).

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953.]

XUM

to 5 per cent., and 10 per cent. white fish-meal, and a further 5 per cent. bran introduced, the mineral supplement being eliminated. In addition treatments 2, 4, and 6 received 2 mg. procaine penicillin in each 1 lb. meal.

The pigs were individually fed twice daily on a scale based on live-weight, the scale for treatments 1, 2, 3, and 4 being that cited by Braude and Foot [5]; this was raised by 15 per cent. in treatments 5 and 6. The dry meal was placed in the feeding troughs and sufficient water added, immediately before feeding, to make a wet mash; water was also available from automatic drinking-bowls. Details of food consumption obtained during the evening feeds of 29/1/52, 30/1/52, and 31/1/52 are summarized in Table 1.

TABLE 1. *Time Taken to Eat Ration* (*mean of three feeds*)

| | *Treatment means* | | | | | | *Coefficient of variation* | *Overall significance of treatment effects* |
|---|---|---|---|---|---|---|---|---|
| | *1* | *2* | *3* | *4* | *5* | *6* | | |
| Live-weight of pigs on 29/1/52, lb. . | 61·8 | 67·4 | 64·8 | 70·8 | 66·4 | 72·4 | 12·653 | None |
| Food consumed/pig/feed, lb. . . | 1·34 | 1·50 | 1·46 | 1·60 | 1·70 | 1·76 | 10·822 | 1% |
| Time taken to eat ration, min. . | 25·7 | 19·6 | 18·5 | 14·9 | 27·9 | 24·6 | 23·258 | 1%* |
| Time taken/1 lb. food, min. . . | 19·6 | 13·9 | 12·7 | 10·0 | 16·6 | 14·9 | 28·213 | 5% |
| Time taken to eat ration, min. (corrected for live-weight differences) | 24·5 | 19·7 | 17·9 | 15·6 | 27·7 | 25·7 | 21·904 | 1% |

* Difference necessary to show significance between any 2 treatment means, at 5% level, = 6·7.

Difference necessary to show significance between 2 means, each of 3 treatments, at 5% level = 3·87.

Difference necessary to show significance between 2 means, each of 3 treatments, at 1% level = 5·28.

Difference necessary to show significance between 2 means, each of 3 treatments, at 0·1% level = 7·14.

*Ad libitum feeding trial with weanling pigs.*—The two dietary treatments tested were the control fish-meal diet already described, and the same supplemented with 2 mg. procaine pencillin in each 1 lb. meal. Group feeding was employed, with nine pigs in each pen, food being at all times available in self-operated dry-meal feeders. Water was obtained from self-operated drinking bowls. The trial was started a few days after weaning, when the pigs were 8 to 9 weeks old. After being paired according to live-weight and litter, so that the two members of each pair were from the same litter and of approximately the same weight, they were allocated at random to the two treatments.

The treatments were replicated four times and for the statistical analysis these have been termed experiments 1, 2, 3, and 4, the method of analysis being similar to that described by Yates and Cochran [6] for serial crop experiments. The analysis of meal consumption per 1 lb.

live-weight increase over the whole period was carried out on the figures obtained for each pen. When, however, the meal-consumption figures are used to compare appetites, it is necessary to measure food consumption over a relatively short period so that there will be little time for differences in live-weights to develop. Accordingly in these experiments food intakes during the first month only have been used for appetite comparisons. In experiments 1, 2, and 4 the two initial treatments were terminated when the control pigs averaged 100 lb. live-weight; the subsequent behaviour of the pigs, on a standard fattening meal, was recorded however. In experiment 3 the differential treatments were continued until slaughter weights were reached, at about 210 lb. The figures for live-weight increase and food consumption up to the 100-lb. stage are given in Table 2, and for live-weight increase from 100 lb. to slaughter in Table 3.

TABLE 2. *Live-weight Gains and Food Consumption (weanling pigs)*

| | | *Experiment number* | | | | | *Coefficient of variation* | *Significance* |
|---|---|---|---|---|---|---|---|---|
| | | *1* | *2* | *3* | *4* | *Mean* | | |
| Live-weight at start of experiments, lb. | control | 32 | 38 | 26 | 23 | 29·8 | .. | .. |
| | penicillin | 32 | 37 | 27 | 23 | 29·8 | .. | .. |
| Daily live-weight gain, lb. (weaning—100 lb.) | control | 1·02 | 1·14 | 1·08 | 0·85 | 1·030 | 14·087 | 0·1% |
| | penicillin | 1·22 | 1·19 | 1·30 | 1·07 | 1·204 | | |
| Meal consumed/1 lb. gain, lb. | control | 3·55 | 3·08 | 3·04 | 3·83 | 3·38 | 2·841 | 5% |
| | penicillin | 3·36 | 2·98 | 2·74 | 3·43 | 3·13 | | |
| Daily meal consumption/pig, during first 4 weeks, lb. | control | 2·52 | 2·55 | 2·39 | 2·14 | 2·40 | .. | .. |
| | penicillin | 2·60 | 3·08 | 2·56 | 2·28 | 2·63 | .. | .. |
| Response to penicillin (as % daily weight-gain of control) | | 19·6% | 4·4% | 20·4% | 25·9% | 16·9% | .. | .. |
| Month in which experiment started | | Jan. | Jan. | Aug. | Aug. | .. | .. | .. |

TABLE 3. *Effect of Removal of Penicillin at 100 lb. Live-weight*
(daily weight-gains, 100–210 lb. live-weight).

| | *Treatment* | |
|---|---|---|
| | *No penicillin throughout* | *Penicillin until 100 lb. live-weight* |
| Experiment 1 | 1·66 | 1·59 |
| Experiment 2 | 1·53 | 1·34 |
| Experiment 3 | 1·52 | 1·59* |
| Experiment 4 | 1·47 | 1·33 |

* Penicillin treatment continued to slaughter.

*Ad libitum feeding trial with fattening pigs.*—In this the same treatments were applied as with the weanling pigs, a control diet containing 10 per cent. white fish-meal, and a supplemented diet with 2 mg. procaine

penicillin in each 1 lb. meal. The treatments were introduced when the pigs were about 100 lb. weight and continued until slaughter, the method of group-feeding being similar to that previously described. The animals were allocated to two pens on a paired litter-mate basis, there being four in each pen. The treatments were duplicated but for statistical analysis have been considered as two treatments with four replications, repeated to give two identical experiments, the data being analysed as a whole, as described by Yates and Cochran [6]. The figures for weight gains and food consumption are given in Table 4.

TABLE 4. *Live-weight Gains and Food Consumption (fattening pigs)*

| | | *Experiment number* | | | *Coefficient of variation* | *Significance* |
|---|---|---|---|---|---|---|
| | | *1* | *2* | *Mean* | | |
| Live-weight at start of experiments, lb. | control | 102 | 109 | 105·5 | .. | .. |
| | penicillin | 102 | 109 | 105·5 | .. | .. |
| Daily live-weight gain, lb. (105–210 lb.) | control | 1·63 | 1·74 | 1·68 | 17·835 | None |
| | penicillin | 1·74 | 1·77 | 1·75 | | |
| Meal consumed/1 lb. gain, lb. | control | 3·90 | 4·52 | 4·21 | .. | .. |
| | penicillin | 3·74 | 3·99 | 3·87 | .. | .. |
| Meal consumed/pig in first 35 days, lb. | control | 282 | 338 | 310 | .. | .. |
| | penicillin | 283 | 328 | 306 | .. | .. |
| Weight gain/pig in first 35 days, lb. | control | 66·8 | 70·2 | 68·5 | .. | .. |
| | penicillin | 71·5 | 70·8 | 71·2 | .. | .. |
| Response to penicillin (as % of daily weight-gain of control) | | 6·7% | 1·7% | 4·2% | .. | .. |

At the conclusion of each of the feeding trials the animals were slaughtered at a bacon factory and carcass measurements made according to the method of McMeekan [7]. For reasons to be discussed later these measurements have not been presented in the present paper.

All the pigs were apparently normal healthy animals, of the Large White breed. They received a supplement of cod-liver oil, fed separately at the rate of 1 oz. per pig each week, from weaning until 100 lb. live-weight. The experiments were carried out at the Agricultural Research Institute (N.I.).

## *Discussion of Results*

*Appetite factors.*—The expression of appetite in pigs is not easy to assess since it is so greatly affected by the palatability of the food and the method of feeding. When pigs are fed twice daily on a basis such as 'the amount of food cleaned up in 15 minutes', a time factor is introduced and food-intake is dictated to a considerable extent by rapidity of eating; presumably under these conditions high palatability of the food will generally lead to increased consumption. Nevertheless, the possibility must be borne in mind that appetite, in terms of zest for food, might sometimes be independent of palatability, so that given a good appetite diets of relatively low palatability could be rapidly consumed. It is in the light of considerations such as these that the effect of antibiotics on appetite merits some study.

The figures in Table 1 indicate that the pigs of treatments 5 and 6 ate for longer than those of treatments 3 and 4 on the same basal diet, due

probably to the extra 15 per cent. of food. On the other hand treatments 1 and 2 (all-vegetable protein diet) took longer than treatments 3 and 4 (10 per cent. fish-meal diet) although the amounts of food were comparable. The difference between any penicillin treatment and its corresponding control is not great enough to be significant, but over the whole experiment the difference between the mean of all the penicillin treatments and all the control treatments is significant at the 5 per cent. level. Ideally such measurements should be made before weight-differences due to treatments have occurred; in the present case differences were already developing between the weights of the various treatment groups and these have affected the results. Analysis of covariance has shown that each 1 lb. increase in live-weight was accompanied by a decrease of 13 seconds in the time taken to eat the appropriate ration. Consequently since the penicillin pigs and the fish-meal pigs were heavier than their controls they ate their food a little more quickly that they otherwise would have done. However, when the treatment means were corrected for differences in weight the difference in time of food consumption between the mean of treatments 1, 3, and 5 and treatments 2, 4, and 6 was still appreciable. It can, therefore, be concluded that under the conditions and weight-range covered by this experiment the pigs receiving procaine penicillin consumed their rations more quickly than the unsupplemented animals, and that the pigs receiving fish-meal ate more rapidly than those receiving only vegetable protein. The amount of procaine penicillin added to the diets was so small as to make it extremely unlikely that the effects obtained were due to enhanced palatibility.

The weanling pigs with unrestricted feeding showed very little evidence of increased food-intake due to procaine penicillin, when receiving the diet containing 10 per cent. fish-meal. Table 2 shows that the mean daily consumption of the supplemented and control pigs, during the first month, were about 2·6 lb. and 2·4 lb. respectively, but the difference is partly due to the treated pigs gaining in weight more rapidly, and it would be very small if the weights were equated. Table 4 indicates that no increase in food-intake occurred when pigs of about 100 lb. weight, receiving the fish-meal diet, were given dietary procaine penicillin.

*Effect of procaine penicillin on weight-gains.*—In the experiments with weanling pigs fed *ad libitum*, the mean weight-gain response to the antibiotic was about 17 per cent. up to the 100-lb. live-weight stage, which was highly significant (Table 2). It has already been indicated that there was little evidence of greater food-intake, on a body-weight basis, so that the response must presumably have been largely due to greater efficiency of food utilization. The trial cited in Table 2 furnishes useful material for studying the relationship between the response to antibiotic, and the rate of live-weight gain with unrestricted feeding, by providing over seventy pigs in well-matched pairs from four replications. A number of regressions have, therefore, been calculated in order to obtain a more accurate description of the following points:

1. The relationship between the live-weight of the pigs at the start of the experiment and their subsequent rate of gain.

XUM

2. The relationship between the live-weight at the start of the experiment and the subsequent response to penicillin.
3. The relationship between the rate of gain and the response to penicillin.

The analyses were carried out so that regression coefficients, with their appropriate tests of significance, could be calculated to show the relationships both between the totals of the individual experiments and between the pairs of pigs within the various experiments. It is on the latter 'within-experiment' regressions that the greater reliance should be placed since they are based on many more degrees of freedom and are less confounded with seasonal effects and litter effects. The details are given in Table 5.

TABLE 5. *Factors Affecting Response of Weanling Pigs to Procaine Penicillin*

| | | *Regression coefficient* | *Significance* |
|---|---|---|---|
| 1. Regression of response to penicillin on initial live-weight | Between expts. . | −1·396 | 5% |
| | Within expts. . | +1·235 | None |
| 2. Regression of response to penicillin on daily weight-gain of control pig | Between expts. . | −64·91 | None |
| | Within expts. . | −75·71 | 5% |
| 3. Regression of daily weight-gain of control pig on initial live-weight | Between expts. . | +0·0117 | None |
| | Within expts. . | +0·0037 | None |

The 'within-experiment' regressions show that the live-weights of the pigs at the start, which varied between 19 lb. and 46 lb. with a mean of 30 lb., had a negligibly small and insignificant effect on the subsequent rate of gain and on the response to penicillin. From the 'between-experiment' regressions, however, there is an indication that the experiments which started with heavier pigs showed a lessened response; although this regression is significant at 5 per cent. level it may be that the relationship has been affected by the time of the year, or other uncontrollable causes which might arise in group-feeding. The second 'within-experiment' regression shows that there was a significant negative relationship between the rate of live-weight gain of the pigs and their response to procaine penicillin. Thus each daily increment of 0·1 lb. live-weight increase in the control pig was accompanied by a decrease of 7·6 per cent. in the response to penicillin; the daily rates of live-weight increase of the control pigs varied from 0·6 lb to 1·4 lb. This inverse relationship just failed to attain significance between experiments. The third regression suggests that the initial live-weights of the control pigs did not materially affect their mean daily live-weight increases from weaning to 100 lb. weight.

In experiment 3 where the treatments were continued until slaughter, at about 210 lb. weight, only a small response of 4·6 per cent. was obtained from the 100-lb. stage, as compared with the initial 20·4 per cent. This confirms our previous observations with restricted feeding [3], in which significant responses were no longer obtained after about

8 weeks' feeding. In experiments 1, 2, and 4 the treatments were discontinued at the 100-lb. stage and all the pigs fed until slaughter on a standard fattening meal containing 2½ per cent. fish-meal, 7½ per cent. earthnut meal, cereals, and a mineral supplement. The figures in Table 3 indicate that in every case the groups originally receiving procaine penicillin made lesser live-weight gains than their controls, after the removal of the antibiotic. Statistical analyses have not been applied owing to the general difficulty in securing high precision in group-feeding trials of short duration, and the consequent difficulty in making due adjustments for the earlier differential weight-gains. The present trends have been confirmed, however, in subsequent individual-feeding experiments, to be reported later.

The live-weight-gain response to procaine penicillin by pigs given the antibiotic for the first time at 100 lb. weight (Table 4) is 4·17 per cent., a figure which is not significant but which is, of course, associated with the limitations inherent in this type of experiment already discussed, and with a coefficient of variation of over 17. These results are supported by earlier findings with individual feeding [3], where late additions of procaine penicillin, at 2 mg./1 lb. meal, were without significant effect.

The carcass measurements of a previous trial [3] showed only small differences between pigs which had responded to procaine penicillin and their controls, and the present series of experiments has resulted in similar findings. It seems probable that the effect of the antibiotic on carcass measurements, under the prevailing conditions, is at the most only small and can thus only be considered adequately when a considerable amount of information has accumulated. For this reason the data from the present experiments have not been presented.

## *Conclusions*

The experiments suggest that procaine penicillin fed to young pigs increases the zest for food, as indicated by greater rapidity in consuming a rationed amount of food. This effect has been observed on diets presumed to be of relatively high and low palatability, but was probably greater with the latter. When food is unrestricted the antibiotic apparently does not promote increased food consumption with the more palatable diet, and weight-gain responses are largely due to increased efficiency of utilization. When young pigs are fed only twice daily, and particularly if the food is not very attractive, procaine penicillin would appear to offer possibilities in increasing the consumption of food as well as the efficiency of food utilization.

There is evidence from the present experiments that a recession may occur if procaine penicillin, having been fed to young pigs for a period, is discontinued. This finding has been confirmed in more recent unpublished trials, and has also been reported from America [8, 9].

Although it has been found that the response to procaine penicillin by weanling pigs is not greatly affected by the actual weaning weights, within the range of about 20 lb. to 45 lb., it is evident that the maximum response is only likely to be obtained, with normal pigs, in the weeks immediately after weaning. After the 100-lb. weight stage the response

XUM

will probably be appreciably less, both with initial and sequential administration.

## REFERENCES


1. K. C. LEPLEY, D. V. CATRON, and C. C. CULBERTSON, Dried Whole Aureomycin Mash and Meat and Bone Scraps for Growing-fattening Swine. J. Anim. Sci., 1950, **9**, 608–14.
2. J. E. BRIGGS and W. M. BEESON, The Effect of Vitamin $B_{12}$, Aureomycin, Streptomycin, or Dried Whey Factor Supplements on the Growth and Fattening of Weanling Pigs. Ibid., 1952, **11**, 103–11.
3. K. L. ROBINSON, W. E. COEY, and G. S. BURNETT, Some Effects of Procaine Penicillin and of Certain Vitamin Supplements on Food Consumption and Live-weight Gain of Pigs. J. Sci. Food & Agric., 1952, **3**, 448–54.
4. —— —— ——, The Influence of the Scale of Feeding on the Response of Pigs to Procaine Penicillin. Chem. & Ind., 1952, **23**, 562.
5. R. BRAUDE and A. S. FOOT, War-time Rations for Pigs. J. Agric. Sci., 1942, **32**, 70–84.
6. F. YATES and W. G. COCHRAN, The Analysis of Groups of Experiments. Ibid., 1938, **28**, 556–80.
7. C. P. MCMEEKAN, Growth and Development in the Pig, with Special Reference to Carcass Quality Characters. Ibid., 1940, **30**, 276–343.
8. C. M. VESTAL, Effect of a Vitamin $B_{12}$-antibiotic Supplement on the Fattening of Hogs. Purdue University Mimeo., 1951, AH–65.
9. L. E. HANSON, E. F. FERRIN, P. A. ANDERSON, and W. J. AUNAN, Growth and Carcass Characteristics of Pigs fed Antibiotics for Part or All of the Growing Fattening Period. J. Anim. Sci., 1952, **11**, 748–9.


(*Received March 26, 1953*)

# SUGAR-BEET CULTIVATION IN AFGHANISTAN AND ITS IMPROVEMENT

GEORG F. HAUSER[1]

THE cultivation of sugar-beet in Afghanistan began on a relatively large scale only about 15 years ago, when in the Baghlan district of northern Afghanistan a beet-sugar factory was built. The farmers planted the beet according to an old-fashioned method (described below), which was in use for other crops like potatoes, cotton, &c.

During the first years of cultivation the yields were quite satisfactory. Most of the beet was planted on virgin soil. The population increased concomitantly with the cultivated area and very soon all the available arable land of this district was put under cultivation. From this time on, about 12 years ago, the sugar-beet yields started to decrease slowly but continuously every year, but those of other crops grown in this district did not decrease. Attempts made to find more new soils for the sugar-beet were partly successful, but they could not compensate for the constant decline of the yields on the old soils. The fact that other crops gave satisfactory yields made it obvious that the old traditional farming practice used for sugar-beet cultivation during all this time was unsuitable.

In these circumstances the first experimental work on sugar-beet cultivation was started in Afghanistan by the author and was continued for two years. In all, four field experiments have been made to determine which method of sugar-beet planting and cultivation is the most suitable under the given conditions. The field trials answered this question clearly and gave interesting sidelights on faults in the traditional farming practices so closely held by the conservative eastern farmer.

*General conditions.*—The soils of the Baghlan sugar-beet district are calcareous loesses and loams with a clay-content ranging between 5 and 20 per cent., those of the latter value being scarce. The humus-content of these soils is low, as is common in very arid climates, and ranges between 1 and 2 per cent. The soils are easily exhausted if not properly fertilized. Inorganic fertilizers have, however, not yet been introduced into the country so that the farmer is entirely dependent on his organic manure, which in general is not sufficient for his land. A natural factor partly compensating for this disadvantage is the remarkable amount of mud brought on to the soil with the irrigation-water in the spring, when heavy rains wash down much material from the mountains.

The crop rotation is arbitrary and irregular and usually includes fallow periods after every second or third year. Green-manuring is impossible since the native plough does not turn the soil, merely scratching it open. Legumes are seldom planted. Under these conditions the producing power of the soil is relatively low. Of course, according to western ideas the whole situation could be improved easily by introducing fertilizers and soil-turning ploughs, also by increasing the

[1] Former Head of the Soil Research Station, Kabul, Afghanistan.

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953.]

XUM

number of livestock, &c., but such fundamental changes are not to be made quickly, especially in such an old conservative farming system. The most urgent need of the sugar industry was the improvement of the beet cultivation, which obviously was suffering under a wrong planting and cultivation method.

*Native cultivation method.*—After the field is ploughed, ridges about 30–40 cm. high, 50 cm. wide, and 90 cm. apart are made with a spade, the ridges being parallel and perpendicular to the direction of fall. A check-flood method of irrigation is used in which the deep, broad ditches between the ridges are filled with water and then stopped up so that they stand full of water.

The beet seeds are soaked in water for 24 hours. The field is pre-irrigated before planting so that the water-line on the sides of the ridges can be seen. When the water has penetrated into the soil the seeds are planted at the water-line in small holes made with a little piece of wood, usually 6–8 seeds to a hole. Both sides of the ridges are sown.

Apart from the great labour involved in building the ridges, an obvious disadvantage is the irregular sowing-depth and the consequent irregular germination. In many places the plants cannot come up because the sowing has been too deep, and a second sowing is usually done on the empty places. The thinning is of utmost difficulty because the young plants stand in groups of 6–10 in one place, and often the tap-root of the remaining plant is broken when the others are taken out.

Another disadvantage is the great width of the ditches, which results in a low plant population. But the most serious disadvantage of all is the impossibility of using hoes for weed-control, because the soil would roll down the steep slopes of the ridges into the ditches and soil would be lost from around the beet plants. The weed-control is done with a small sickle-shaped knife which cuts the weeds at the surface of the soil, leaving them to grow again immediately.

The only advantage of this system for the farmer is that the levelling of the soil on a sloping field is not necessary.

It is obvious that this method is suited for gardens but not for large fields, and that, owing to the low population, it can give high yields only if the beets become very large. Large beets with high sugar-content require a very fertile soil, a condition which cannot be reached in a short time under the given circumstances.

To find the most suitable method of planting in these conditions, the native method described above was compared in field experiments with the two following planting methods:

*Furrows.* The beet was sown in rows on flat ridges. Small irrigation ditches were made after every second row. The two rows on each ridge were 35 cm. (13·8 in.) apart, and the distance from row to row across the ditches was 55 cm. (21·7 in.). The weed-control was done by ordinary western beet-hoes.

*Flat soil.* The beet was sown on flat soil in straight rows 45 cm. (17·5 in.) apart. Irrigation was done by check flooding, because this is the most common practice in the country and therefore well known to the farmer.

*Field Trials*

Within two years four large field experiments were carried out, in two of which all three planting methods, mentioned above, were compared; in the other two field trials only the native method and the flat-soil planting were compared, since the latter was by far the most promising. In all experiments three or more replications were made. The plot sizes were 120–30 sq. metres in all cases. In accordance with the normal native practice the crops grown before the trials were wheat or barley, no fertilizers were used, and the field work was done with native implements or by hand, since only these means are at the native farmers' command.

The soils were the medium loessy loams common in the sugar-beet district. As seeds the Danish type Eagle Hill was distributed to the farmers and was also used in the experiments.

One of these field trials was surely an extraordinary one (field No. 3), and needs the following explanation: the weeds are a great evil in the Baghlan area. There is also a shortage of farm labour in the district, especially during the periods of intensive farming activity. It therefore often happens that a farmer cannot clean his beet fields at the proper time, and the weeds overgrow the young beet plants surprisingly quickly. In some years this happens in many fields. It was reasonably assumed that in such cases the young beet on flat soil would be damaged more seriously than that on the relatively high ridges of the native planting method. Therefore on this field No. 3 the hoeing and cleaning work was also delayed in the same way as sometimes happens on farmers' fields. Accordingly, the yields in the experiment field were less than the others and showed the effect of the planting methods in these unfavourable conditions.

*Irrigation.*—Irrigation water is a limiting factor. All changes in agricultural practice which lead to a greater water-consumption are *a priori* unfit for the country because they would diminish the irrigable area of the district. For this reason the water supplied to the experimental fields was measured exactly for every plot by means of a measuring weir. It was found that the average amounts of irrigation-water consumed in these experiments were as follows:

Native planting method: 103·2 cm. = 40·7 acre-inches (total per season.)
Furrow planting method: 70·0 cm. = 27·5 acre-inches (total per season)
Flat soil method: 104·1 cm. = 41·0 acre-inches (total per season).

Thus the furrow method was the most water-saving. Undoubtedly this was because of lower evaporation losses in the small furrows. The other two methods consumed virtually equal amounts of water. The furrow method has, however, the disadvantages that it is difficult for the farmer to make suitable small furrows by hand, and the yields are comparatively low (see below).

*Germination and plant development.*—Needless to say, the plant

development was observed carefully during the whole growing-season. First of all, the germination in the native method was unsatisfactory even though this method was best known by the farmers who did the work; counts showed that in 16–45 per cent. of the sowing-holes no plants came up. In all cases a second sowing was necessary in order to fill these empty places. Moreover the plants developed at irregular rates. The sowing in rows of the two other methods gave no difficulties in these respects.

The first development of the young plants was by far the best in the flat soil, somewhat poorer in the furrow plots, and very irregular and slow in the native ridge method. The thinning was very slow and difficult in the native plots and quick and easy in the other plots. After the thinning, the plants developed quickest and best in the flat soil. There the leaves covered the soil quickly. This took a longer time in the furrow plots and the soil of the native plots was never completely covered and shaded by the leaves.

In about August this picture changed in all experiments. Whilst on the native plots the leaves went on growing much faster than the roots, the leaves in the other plots grew more slowly and the roots thickened quickly. One month before harvest the native plots looked best owing to the heavy foliage but had poor roots; and the flat-soil plots looked poorest because of their poor foliage, but they had the heaviest roots. The furrow plots were intermediate between these extremes. (This misleading appearance caused many misjudgements by native farmers.) The real superiority of the flat-planting method under the given conditions was shown by the yields.

*Yields.*—The yields from all plots were weighed separately and immediately afterwards the sugar-content was determined in the factory's laboratory. The results were as follows:

*Averages of the Replications*

| | *Yields of beet metr. tons/hectare* | *% sugar in beet* | *Yields of sugar kg./hectare* |
|---|---|---|---|
| *Field* 1. | | | |
| Native | 24·4 (100%) | 17·0 | 4,150 (100%) |
| Furrows | 26·6 (109%) | 17·6 | 4,680 (113%) |
| Flat soil | 34·2 (140%) | 17·3 | 5,920 (143%) |
| *Field* 2. | | | |
| Native | 27·3 (100%) | 17·9 | 4,900 (100%) |
| Furrows | 30·2 (111%) | 19·5 | 5,910 (121%) |
| Flat soil | 36·9 (135%) | 18·6 | 6,860 (140%) |
| *Field* 3 (delayed hoeing). | | | |
| Native | 12·1 (100%) | 16·0 | 1,938 (100%) |
| Flat soil | 24·4 (201%) | 15·6 | 3,810 (197%) |
| *Field* 4. | | | |
| Native | 33·6 (100%) | 17·1 | 5,750 (100%) |
| Flat soil | 44·0 (131%) | 18·3 | 8,060 (140%) |

The figures in parentheses show the yield increases when the yields of the native plots are taken as 100.

The enormous superiority of planting in flat soil over the other methods is obvious. Even so, the yields, despite the ideal Afghan climate, are poor compared with those of some beet districts in the western world. This is because of the poor unfertilized soil. (Fertilization makes an additional increase in yield of about 70 per cent., as shown in other experiments.) The cause of these higher yields on the flat plots is, in the first place, the larger population of beets (about 60–70 per cent. higher than by the native method). Secondly, the water-supply for the plants in the flat soil was better because the leaves covered the soil, prevented evaporation losses, and kept the soil soft; whilst by the native method the soil gets superficially very dry and hard between the irrigations. The beets of the flat soil were generally smaller but well shaped and long, which accounted for the higher sugar-content; on the native ridges the beets were somewhat shorter, thicker, and often curved owing to their position on the slope of the ridges, and very often had 'two feet'. The latter fault was caused by the breaking of the tap-root in thinning (*v.s.*), or was the plant's defence against the loosening of the soil on the sloping side of the ridges.

The beets of the furrow plots were typically intermediate to those of the two other methods. Since this method of planting is also an intermediate between flat soil and the high ridges of the native method, it confirms the conclusion that under the given conditions the sowing of beet in flat soil is by far the most suitable method.

Another great advantage of the flat planting is the remarkably smaller amount of working time necessary to keep a field in good shape. The different kinds of work were timed, and the times taken are compared in the following table. The time required by the native method is shown as 100 per cent. and the times by the other methods are calculated on this basis.

| | *Native* | *Furrows* | *Flat soil* |
|---|---|---|---|
| | *per cent.* | *per cent.* | *per cent.* |
| Preparation of field after ploughing . . | 100 | 60 | 15 |
| Sowing . . . . . | 100 | 120 | 120 |
| Thinning . . . . . | 100 | 40 | 40 |
| Weed control . . . . . | 100 | 55 | 35 |

Only the hand-sowing of rows took more time than the corresponding native method. All other phases of the work were done more quickly (and also much better) on the furrow plots and flat-soil plots.

### *Conclusion*

The experiments have shown clearly that in the general conditions under which sugar-beet must be cultivated in the Baghlan district, sowing in rows in flat soil is by far the best method. If the fields are treated properly this method will give a yield increase of about 30–35 per cent. of beet and about 40 per cent. of sugar. If the fields are not properly

XUM

cultivated (owing to shortage of farm labour or other causes) then the yields will, of course, be lower (see figures of field No. 3); but in such cases the flat-sowing method shows an even greater advantage over the native method than in cases of proper cultivation. The flat planting will enable the farmer to handle more fields with less labour and with no new equipment. It is, therefore, an easy and quick way to secure a marked increase in the yield of beet and sugar.

(*Received April 17, 1953*)

# THE P.F.R.A. AND A NEW PRAIRIE AGRICULTURE

L. B. THOMSON[1]

WITH PLATE 10

## *Introduction*

IN 1935 all was not well on the Canadian prairies. Newspapers in Britain and eastern Canada carried articles on the devastating dust storms that were rolling across western Canada. They printed pictures of homes almost smothered in drifts of top-soil and concluded that Canada, as a wheat-growing country, was finished.

It was during this same year that the Government of Canada passed its Prairie Farm Rehabilitation Act. Under the provisions of the Act the organization, now generally referred to as P.F.R.A., was first set up in Swift Current, Saskatchewan, in the centre of the trouble zone.

At its inception P.F.R.A. was closely associated with the Federal Experimental Farms Service. Together, the established Experimental Farms Service and the new P.F.R.A. organization acted as co-ordinators of the efforts of the prairie universities, the provincial departments of agriculture, rural municipalities, other federal agencies, and the farmers themselves upon the formidable task of finding and applying the answers to immediate drought problems of soil drifting and water-supply. At this time consideration was also given to long-term planning.

Over the last 17 years the programmes resulting from the above policy have brought about a new and more permanent prairie agriculture. The knowledge and experience gained over this period continue to shape the policy of conservation of soil and water resources aimed at the eventual complete rehabilitation of the land and the people.

*Early work.*—The most serious and urgent problem that confronted the organizations in the early years of the P.F.R.A. was that of soil drifting. In spite of the fact that many people pessimistically predicted that grain farming was destined to reduce the prairies to a desert, the Experimental Farms Service of Canada began the application of experimental knowledge to the problem of controlling drifting soil. Drawing on the experience of farmers and employing every scientific aid in the problem, answers to the dangerously drifting areas were soon found. These areas were not large compared with the total acreage of the prairies. From the wind tunnel experiments it was learned that a 15-miles-per-hour wind would transport particles of soil from an exposed surface. By not disturbing a 6-in. stubble it was noted that the wind velocity was reduced by 3 miles per hour and soil was no longer moved.

From this developed the concept of 'trash-cover farming' whereby stubble would no longer be turned under by cultivation. Some form of sub-surface cultivation was needed. Inventive minds soon produced the necessary implements to accomplish this and wherever the combines

[1] Director, Prairie Farm Rehabilitation Act, Canada Department of Agriculture, Regina, Sask.

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953.]

3988.84 U

XUM

left a good stubble it was anchored in the soil and prevented the abrasive action of the wind on the soil particles.

In many cases, however, crops were poor in consecutive years and the exceedingly thin stubble which resulted was hopeless as a deterrent to soil erosion. To overcome this the soil at greater depths was turned by deep tillage implements and left in large, cloddy lumps which effectively reduced wind erosion.

Strip cropping, too, became of great importance. Alternate, parallel strips of fallow and cropped land lying crosswise to the path of prevailing winds did much to counteract soil drifting. Today flying across the western prairies the traveller is presented with a vista of strips converging into the distance for as far as the eye can see (Plate 10, Fig. 1).

All the methods described above were co-ordinated under different soil and climatic conditions and soon produced favourable results.

*Agricultural improvement associations.*—Concurrently with the work of the Experimental Farms the P.F.R.A. was assisting farmers to organize themselves into Agricultural Improvement Associations. Through these Associations the farmers, along with agricultural officials, planned the application of the corrective methods devised by the Experimental Farms.

*Experimental Farms substations.*—Meanwhile, the Experimental Farms Service was setting up substations on 640-acre units on private farms throughout the prairies. The purpose of the substations was to seek out the best dry-land farming practices for local soil types and climatic conditions. Experienced farmers did the work on these farms, combining scientific findings of the Experimental Farms with their own intimate knowledge of local conditions. In this way the substations became the outposts of agricultural science and, in the writer's judgement, one of the most valuable means of agricultural extension and education ever initiated in Canada.

*Soil moisture.*—As a result of research carried out since 1920 a fundamental aspect of drought and soil drifting has also been given a great deal of attention. This is the factor of soil moisture. It was early discovered that the prairie rainfall during the growing season could not produce an economic crop. This situation is further aggravated by the evaporation of soil water in years of lower-than-normal rainfall. Research findings indicated that fallowing the land allowed extra reserves of moisture to accumulate in the soil sufficient to produce a crop the next year.

It should, perhaps, be noted here that generally moisture and not fertility is the factor governing growth on prairie soils. Just how long this situation will continue is open to question but the fact remains that grain has been grown continuously, with the exception of alternate summer-fallows, for a period of more than 50 years. To this time there has been no appreciable drop in yields attributable to the depletion of fertility.

The co-ordinated work of governments, local bodies, and farmers on the problems of soil drifting and soil moisture, has, over the years since the great drought of the 'thirties', produced a new approach to dry-land farming. While P.F.R.A. provided financial aid and was the chief

co-ordinating influence in this work, the main stem through which extension programmes were undertaken was the Experimental Farms Service of the Canada Department of Agriculture. Wherever possible the policy was aimed at utilizing existing services and thus preventing needless duplication of effort.

*Water development.*—Within P.F.R.A. itself work was early instituted to develop prairie water resources both as a supplement to dry-land farming as well as for small-scale irrigation.

Up until 1929 the Dominion Irrigation and Reclamation Service provided engineering assistance to farmers in the matter of supplying water for domestic needs and for livestock. At this time, however, the problem of developing water resources was transferred to the provincial governments. Through the early part of the 'thirties' it was discovered that the provinces were unable to cope with the situation and the need for a similar service to that operated by the Dominion Irrigation and Reclamation Service became very apparent. This work was undertaken by P.F.R.A.

In the first year of operations P.F.R.A. provided engineering services necessary for the installation of small dams and the excavation of dugouts. The latter were simply small excavations, strategically located, to catch the run-off waters from snow melt. The basic idea behind the plan was to conserve spring run-off for use through the summer period when rainfall was uncertain and frequently inadequate even for the needs of stock and the farm household.

The Government of Canada realized that the financial outlay involved was often beyond the means of the average farmer, and through P.F.R.A. financial assistance on a self-help basis was provided.

Since its inception in 1935, up until March 1953, P.F.R.A. has assisted in the construction of 48,324 small water-development projects. Of this number 39,544 are dugouts, 6,077 are stock-watering dams, and 2,703 are small irrigation projects.

While it is difficult to determine accurately the exact acreage irrigated by the small irrigation projects, it is conservatively estimated that 120,000 acres are irrigated on individual farms spread over a wide area of the prairies.

In addition to the development of water-storage projects on an individual farm basis P.F.R.A. also undertook work on small watersheds. Such work usually involved small earth dams constructed at the request of a local water-users' association or a rural municipality. Assuming the suggested projects were sound from an engineering point of view, and could adequately service the needs of the community of people involved, they would be built. The P.F.R.A. assumed the capital cost involved in the reservoir but the distribution systems were the responsibility of the water-users' association or in some cases the provincial government. These projects are known as Community Projects. Up to March 1953, 256 community projects have been constructed for irrigation, stock-watering, and domestic needs.

*P.F.R.A. Projects.*—In 1936 a concentrated effort was made to develop irrigation projects in south-western Saskatchewan and southern

XUM

Alberta. In these areas drought conditions had made serious inroads on the livestock population and the uncertainty of future feed supplies threatened to reduce stock numbers even further.

Among the projects undertaken were those of Val Marie, Eastend, Consul, and Maple Creek in the Province of Saskatchewan. In these areas the Government of Canada purchased the land and through P.F.R.A. assumed full responsibility for all development. To the present time P.F.R.A. has maintained and operated the areas. A water rate of $1·50 per acre per annum is levied to cover operation and maintenance costs.

Originally the land was leased to the farmers, but, as time went on and the people made a success of the undertaking, agreements of sale were allowed. The sale price of the land included the water right and all costs for land improvement which was done at cost by P.F.R.A.

This programme, designed to give immediate assistance to some of the worst of the drought-stricken regions, has produced very satisfactory results. A recent appraisal of the projects shows that their capital cost has been fully justified. A safe and sound livestock economy has resulted.

The Val Marie Project provides a good illustration of the achievements in this section of P.F.R.A. activity. In 1937 it was necessary to ship in a trainload of hay from eastern Canada to feed the livestock in the area. Cattle were forced on to the market and sold for one-half to two cents per pound. Of the total cattle population only 250 head remained. By 1952, through the benefits of irrigation, Val Marie was carrying 4,000 head and the people are no longer plagued by fears of insecurity in dry seasons.

Despite the attendant difficulties and the gradual nature of the overall development, all these P.F.R.A. projects have paralleled the achievements at Val Marie. In all, over 2,500 farmers have been rehabilitated on these projects.

*Community pastures.*—For many people the dry years were something that could be escaped. Moves to areas endowed with a wetter climate were frequent. Other people again were assisted by the Government to make these moves and numbers of them were resettled on irrigation projects as well. With the coming of the major irrigation and reclamation projects (which will be discussed later) more and more people were and are being shifted from areas of continuous crop failure to irrigated lands and economic security.

But what of the thousands of acres of land they left behind? Here indeed was a problem. The dry, weedy, unproductive land was a liability.

In 1937 an amendment was introduced into the Prairie Farm Rehabilitation Act whereby P.F.R.A. was given powers to reclaim these territories.

Once again in co-operation with the Experimental Farms Service, regrassing programmes were worked out. P.F.R.A. undertook all capital construction involving fencing, watering facilities, corrals, and buildings.

By 1953 1,652,020 acres were enclosed in sixty operating pasture units. From a liability in 1937 this land was improved so that by 1952 it was carrying 93,207 head of cattle during the summer months.

Each pasture is supervised by a P.F.R.A. pasture manager while the grazing is allocated by an advisory committee appointed by the patrons. Careful management of the pasture-grazing resources is given primary consideration. Those farmers taking advantage of the pasture facilities can then devote their land to other uses. As far as his livestock is concerned the farmer need only consider the production of feed and limited pasturage for the winter months.

Pasture services, including dehorning, spraying, vaccination, castration, &c., are provided at cost. A grazing fee of $0·75 per month is levied on cattle. For horses, which are few in number, the fee is $1·00 per month, and for sheep $0·07 per month exclusive of shepherding.

An important phase of the community pasture work has been the provision of good quality bulls. At the original request of the pasture patrons the Government of Canada has, since 1938, purchased 1,190 bulls. The returns in breeding fees have more than paid for operating and overhead costs. At the same time the policy has resulted in a notable improvement in the type and quality of cattle owned by the patrons.

The pasture advisory committees have, on their own initiative, organized many useful services such as marketing policies and auction sales. In 1952, 35 out of 59 operating pastures carried livestock insurance on a total of 51,477 head. Losses amounted to 299 or one-half of 1 per cent.

While community pastures have done much to reclaim and utilize the once vacated, depleted lands of the prairies, a great deal still remains to be done. Recent research has indicated that new grasses for reseeding, such as Russian wild rye (*Elymus junceus*), intermediate wheat grass (*Agropyron intermedium*), and others, can advantageously be co-ordinated with existing stands of crested wheat grass (*Agropyron cristatum*) and native grasses in the grazing economy. There appears to be little doubt that within a few years the community pastures can double their present carrying capacity.

### *Major Irrigation and Reclamation*

Since it was inaugurated P.F.R.A. has given assistance in a wide variety of activities. Soil surveys, economic land-use studies, and tree-planting programmes are but a few. While these may appear distant and unrelated to community pasture development and other undertakings as outlined above, all the work does have the common objective of providing an immediate and a long-term solution to the problem of prairie rehabilitation.

In 1935 it was recognized that it is not possible to cure all the ills of drought in a matter of a year or so. With this in mind P.F.R.A. instituted a number of major surveys and investigations aimed at utilizing prairie water resources for large-scale irrigation. This was the beginning of an important section of P.F.R.A. work, the end-results of which are just beginning to bring a new era to large tracts of prairie land.

*St. Mary Project.*—In 1951 a 4,000,000-cubic-yard earth dam was

officially opened in southern Alberta. Behind this structure 320,000 acre-feet of water are stored. When the associated diversions and distribution systems are completed the project will ultimately bring water to 519,000 acres of land between Magrath and Medicine Hat (Plate 10, Fig. 2).

The opening of this project marked the first time in the history of Canada that a major irrigation project had been undertaken with a Federal authority, a provincial government, and the farmer all working in partnership.

Under the agreement Canada assumed responsibility for the major storages eastward from the watershed to a point known as Ridge Reservoir. From here on, the responsibility was Alberta's to see that construction, colonization, and settlement was carried out. A charge is made by the Government of Canada to provide for the operation and maintenance of capital work. This charge is passed on to the farmer by Alberta in what is known as annual water charges. In addition the province in its colonization plan charges a water-right fee per acre to farmers acquiring land. Such revenue is returnable to Alberta.

Up to March 31st, 1953, approximately $21,300,000 had been spent on the St. Mary Project. Of this amount, $8,800,000 was contributed by Alberta and $12,500,000 by Canada. While the investment by governments is substantial it should be realized that the farmers developing the land will likewise make a big investment. After all the land is improved and on a sound irrigation economy, the total farmers' investment will exceed that of both governments. It is expected that the project will be fully completed by 1955.

*The Bow River Project.*—In 1909 a British company, known as the Canada Land and Irrigation Company, began construction on an irrigation project south and east from Calgary. It was intended to irrigate 240,000 acres, but up to 1949 only 57,000 acres had been irrigated. The Company was in difficulties and unable to complete the project.

After extended discussions between the Company and the governments of Alberta and Canada as to the completion of the project, the Government of Canada decided to purchase the assets of the Company. These negotiations were finalized in 1950 and during 1951 and 1952 the Government of Canada, through P.F.R.A., has embarked on a programme of renovation and enlargement of existing canals and dams. Already 15,000 additional acres are under irrigation and by the 1953 season another 25,000 acres will be ready. By 1954 a 70,000-acre block, known as the Western Section, will be receiving water.

The main purpose of this extensive development is to resettle farmers from the crop-failure areas of the prairies. This was referred to earlier in that portion dealing with community pastures.

### *Other Major Irrigation and Reclamation Projects*

Following the policy of exploring all possible opportunities for the large-scale development of water resources, P.F.R.A. is currently investigating the proposed Red Deer River Project in Alberta and the South Saskatchewan Project in Saskatchewan. Each of these projects

could irrigate an estimated 500,000 acres. Both are multi-purpose in that power, domestic water-supply, and recreation are combined with the primary function of supplying irrigation water.

The major projects discussed above are financed by special vote of Parliament rather than out of the annual P.F.R.A. appropriation. P.F.R.A. provides all the engineering services and supervision for their proper administration.

This same procedure is followed for the Special Projects discussed hereunder. The Special Projects are outside of the P.F.R.A. area and are the result of requests made to the Government of Canada by the provinces concerned.

### *Special Projects*

The P.F.R.A. area has as its base the 49th parallel and its northern boundary follows a rough triangular pattern starting at the British Columbia–Alberta border near Calgary and running north-east to Lloydminster and then south and east again to join the International Boundary south of Winnipeg, in Manitoba. Outside of this, P.F.R.A. is operating under special vote of Parliament in the provinces of British Columbia and Manitoba.

*British Columbia Projects.*— A number of irrigation projects have been undertaken in British Columbia for the Veterans' Land Act Administration of Canada. Under this programme over 2,600 acres of new land has been irrigated for the rehabilitation of veterans of the Second World War. The land is divided into small units from 1 to 10 acres in size and most of the land has now been settled by Veterans' Land Act.

Other projects requested by the British Columbia Government are currently under investigation.

In the Lillooet valley, near Pemberton, frequent flooding has caused many difficulties and crop losses for the settlers, the majority of whom are veterans of the First World War. P.F.R.A. has practically completed drainage, dyking, and erosion control work in this region and in total over 14,000 acres of land have been reclaimed. Owing to the fact that the area in question is close to Vancouver there is every reason to believe that it will be intensively farmed to meet the already high and rapidly increasing demand for fresh farm products.

*Manitoba Projects.*—At the request of the Manitoba Government the P.F.R.A. has engaged upon a problem of flood control and sedimentation along the lands to the east of the Riding Mountain escarpment. The work, which has been concentrated in the Edwards Creek, Mink Creek, and Wilson River areas, has involved the construction of channel cut-offs, dyking, and bank-erosion control. In addition to the engineering problems, the root cause of the trouble lies in a large part within the Riding Mountain National Park. Ecological and geological changes which have occurred in this area over the last 50 years require intensive study by trained specialists. This work is likely to be started in the near future.

Elsewhere in Manitoba, along the Assiniboine River, P.F.R.A. has, over the past 2 years, been engaged on detailed investigations of the

XUM

Assiniboine flood problem. The Assiniboine is a tributary of the Red River, which flows through the heart of Winnipeg City. It may be recalled that in 1950 Winnipeg suffered a devastating flood when the Red River carried over 100,000 cubic feet per second. Information on the Assiniboine, which is currently being assembled and analysed, will be presented to the Resources and Development Department which has the overall responsibility for the flood problem on the Red River and its effect on Winnipeg and district.

At the present time an important investigation is being conducted on lands bordering the Saskatchewan, Carrot, and Pasquia rivers near The Pas. Investigations for the Pasquia area have been completed and they show that the reclaiming of 135,000 acres of land is economically and engineeringly feasible. Construction of dykes in the Pasquia area would give protection from spring flooding to land currently farmed as well as extensive tracts capable of development. Work on the project is commencing in 1953 and will require 3 years for completion.

*Auxiliary services.*—It can readily be understood that the size and complexity of many of the P.F.R.A. projects must necessarily involve a great deal of diverse technical knowledge and skill. As far as possible the policy is to gather this information and services from existing organizations. When such information is not available, P.F.R.A. establishes its own division. At the present time there are six such divisions operating. They cover hydrology, design, survey exploration, drainage, and soil mechanics. Further to these is a recently-established Division of Air Surveys and Engineering Geology.

The interpretation of aerial photographs by the above division has resulted in major savings of time and money to the organization. It has been of assistance to engineers, agriculturalists, and geologists alike.

In addition to the above services, the organization frequently employs consultant engineers both from within Canada and from the United States of America.

Within P.F.R.A. there has been a recognition of the value of coordination between engineering and agriculture. Indeed, the well-being of any project involving the conservation and development of soil and water resources is vitally concerned with a firm union between engineering and agriculture.

## *Conclusion*

During the past 17 years definite progress has been made in the problem of rehabilitation on the prairies. The role of P.F.R.A. in the overall picture has been an important one. However, other departments of government, both Federal and Provincial, have also made valuable contributions. But beyond the departments and organizations is the farmer, who in the long run is the person who will decide the success or failure of any scheme of conservation. It is necessary, therefore, that in any planning he should have a full and thorough understanding of what is involved and what may be achieved.

(*Received May 22, 1953*)

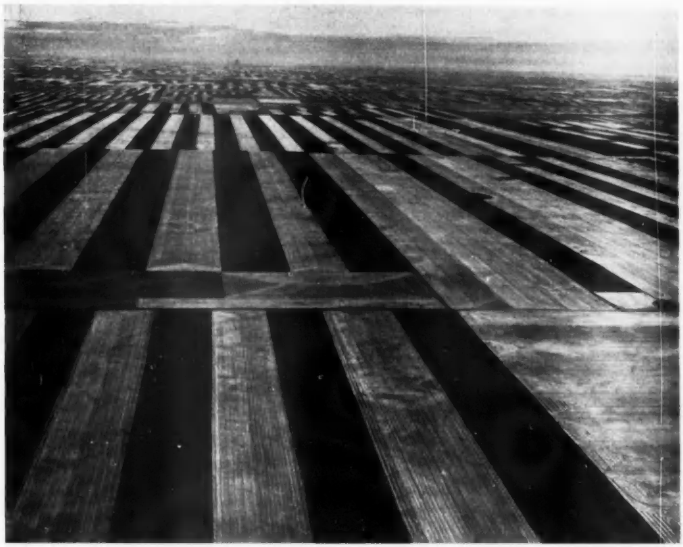


FIG. 1. Stretching northwards as far as the eye can see, the pattern of strip cropping in Alberta gives an indication of the changes in farming technique which have come to the prairies. Combinations of fallowing, strip cropping, and trash cover help to combat drought and wind erosion

*Photograph P.F.R.A.*

FIG. 2. St. Mary Dam and Reservoir. Capable of impounding 320,000 acre-feet of water, the St. Mary Dam is the key structure on an irrigation project ultimately capable of bringing water to over 500,000 acres in southern Alberta

# EFFECT OF WEEDING ON THE YIELD OF WHEAT

H. K. PANDE

(*Department of Agronomy, B.R. College, Agra, India*)

To the farmer in India the problem of weed control may be little disturbing provided its seriousness impresses him in time; he can use the cheap and abundant labour supply that can very well combat the obnoxious weeds by cultural methods, and he may not have to apply chemical control, which necessitates some technical ability. As Bates [1] states: 'Efficient as some of the new chemical sprays and weed killers may be, the maxim, prevention is better than cure, still holds good.' The primary aim, therefore, should be to maintain clean land, which is made easier by suitable methods of cultivation.

*Technique and material.*—To test the effectiveness of weeding on wheat, an experiment was conducted at Balwant Rajput College, Agricultural Research Farm, Bichpuri (Agra) during the three successive *Rabi* (winter) seasons of 1949–50, 1950–1, and 1951–2. The crop was drilled using the country plough to which was attached a seeding spout known locally as *Nai*. Sowing-time, seed-rate, and the period between sowing and weeding were maintained uniform during the 3 years. Weeding followed the first irrigation given to the crop 1 month after sowing; it was done 10 days after irrigation when the soil could be cultivated, and was finished in 2 days. At this time, before weeding, the number of crop plants and weeds (species-wise) were estimated in each plot using a quadrat of 1 yard size. Three random quadrats per plot were thrown when the counts were made. After reaching maturity, five plants from each plot were taken out for studying their characters; the crops on the individual plots were harvested separately, threshed, and winnowed, and the grain was weighed.

Since the final yield is determined by the grain produced per plant, which in turn is the result of the ear-bearing tillers, the discussion in the present paper is confined to the observation of these characters. The data for grain yield per acre, grain yield per plant, and ear-bearing tillers per plant for each year were statistically analysed following the method of analysis of variance due to Yates [2]. All the interpretations are based on the significant difference between means. The results for the 3 years are given in Tables 2, 3, and 4.

## *Experimental Results*

Count of the weed population indicated that there was a fairly uniform stand of weeds in all the plots. The weeds enumerated in Table 1 were competing with the wheat crop.

*In 1949–50* the relative response to weeding of three varieties of wheat, Local, C 13, and Pb 591, in the production of grain yield was studied. Each variety was subjected to two treatments, weeding and no-weeding,

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953.]

with three replications, making in all eighteen plots each of 1/64 acre (45 × 15 ft.). At sowing-time of wheat the soil contained 0·084 per cent. of nitrogen on the dry basis.[1]

TABLE 1. *Density of Crop and Weed Species (per sq. yard) and Their Proportion to Total Population*

| *Crop and chief weeds present* | *1949–50* | | *1950–1* | | *1951–2* | |
|---|---|---|---|---|---|---|
| | *No. of plants* | *% of total population* | *No. of plants* | *% of total population* | *No. of plants* | *% of total population* |
| 1. Wheat . . . | 96·4 | 26·31 | 85·4 | 48·76 | 103·8 | 26·80 |
| 2. *Chenopodium album* . | 172·2 | 47·01 | 34·7 | 19·90 | 80·0 | 20·66 |
| 3. *Asphodelus tenuifolius* | 37·6 | 10·26 | 21·1 | 12·10 | 43·7 | 11·28 |
| 4. *Melilotus* sp. . . | 41·2 | 11·24 | 11·9 | 6·82 | 104·3 | 26·94 |
| 5. *Convolvulus arvensis* . | 4·0 | 1·09 | 14·4 | 8·26 | 21·0 | 5·42 |
| 6. *Anagallis arvensis* . | 8·5 | 2·32 | 0·2 | 0·11 | 2·4 | 0·62 |
| 7. *Vicia* sp. . . . | 5·2 | 1·41 | 0·2 | 0·11 | 2·7 | 0·69 |
| 8. *Cyperus rotundus* . | 1·2 | 0·32 | 6·8 | 3·90 | 29·3 | 7·56 |

It is evident (Table 2, Fig. 1, 1949–50) that the plants from the weeded plots showed significantly (1 per cent.) higher grain weight and more ear-bearing tillers per plant than those under non-weeded plots. The grain yield per acre of the weeded crop of wheat was also significantly (1 per cent.) more than that of the non-weeded one. Weeding brought about an increase of 24·3 per cent. in grain yield per acre, 46·6 per cent. in weight of grain per plant, and 29·6 per cent. in the number of ear-bearing tillers per plant. The differences among the varieties were significant only for the ear-bearing tillers per plant (Table 3). The Local proved significantly superior (1 per cent.) to Pb 591 and C 13, and Pb 591 was superior (5 per cent.) to C 13. Pb 591 was finally selected for further trial, as C 13 was inferior to this, and Local, a mixture of many types, though superior in one respect (ear-bearing tillers per plant) failed to increase the yield.

*In 1950–1* only Pb 591 was put under trial with increased number of replications, viz. eight, thus giving greater precision to the effect of the weeding treatment. The layout comprised one variety, two treatments of weeding and eight replications, making in all sixteen plots each of 1/60 acre (33 × 22 ft.). The chemical analysis of the soil[1] at sowing-time of wheat showed 0·067 per cent. N, 0·149 per cent. total $P_2O_5$, and 0·966 per cent. $K_2O$ on the dry basis.

The effect of weeding was significantly marked (5 per cent.) in increasing the grain weight and number of fertile tillers per plant and grain yield per acre of weeded crop, as compared with the non-weeded. Weeding increased the yield of grain per acre by 22·9 per cent., the grain weight and number of fertile tillers per plant by 26·6 per cent. and 33·3 per cent. respectively (Table 2, Fig. 2, 1950–1).

[1] Composite soil samples were taken from surface to 9 in. depth.

TABLE 2. *Three Years' Results of the Effect of Weeding on Yield of Grain per Acre, Yield of Grain per Plant, and Number of Ear-bearing Tillers per Plant in Wheat*

| Treatments | Yield of grain per acre | | Yield of grain per plant | | No. of ear-bearing tillers | |
|---|---|---|---|---|---|---|
| | Wt. of grain lb. | Increase over no-weeding % | Wt. of grain gm. | Increase over no-weeding % | No. of tillers | Increase over no-weeding % |
| 1949–50 | | | | | | |
| Weeding | 1,731 | 24·3 | 5·63 | 46·6 | 3·85 | 29·6 |
| No-weeding | 1,393 | .. | 3·84 | .. | 2·97 | .. |
| Critical difference | | | | | | |
| at 5% | 251 | .. | 1·19 | .. | 0·59 | .. |
| at 1% | 356 | .. | 1·70 | .. | 0·78 | .. |
| 1950–1 | | | | | | |
| Weeding | 1,090 | 22·9 | 3·47 | 26·6 | 3·20 | 33·3 |
| No-weeding | 886 | .. | 2·74 | .. | 2·40 | .. |
| Critical difference | | | | | | |
| at 5% | 161 | .. | 0·55 | .. | 0·60 | .. |
| at 1% | 238 | .. | 0·82 | .. | 0·89 | .. |
| 1951–2 | | | | | | |
| Weeding (hand-hoe) | 1,234 | 27·8 | 4·41 | 86·0 | 3·85 | 67·3 |
| Weeding (hand-pulling) | 1,157 | 19·8 | 4·51 | 90·2 | 4·05 | 76·0 |
| No-weeding | 965 | .. | 2·37 | .. | 2·30 | .. |
| Critical difference | | | | | | |
| at 5% | 103 | .. | 1·70 | .. | 0·82 | .. |
| at 1% | 142 | .. | .. | .. | 1·40 | .. |
| 1951–2 | | | | | | |
| High fertility | 1,690 | 208·5 | 5·36 | 121·4 | 4·20 | 67·3 |
| Low fertility | 548 | .. | 2·42 | .. | 2·51 | .. |
| Critical difference | | | | | | |
| at 1% | 138 | .. | 1·34 | .. | 0·93 | .. |

*In 1951–2* two methods of weeding were adopted. Previously it was done with the help of a hand-hoe which besides removing weeds helped to create mulch. To find out if the crops were affected by freedom from the competition of the weeds or by the production of mulch, the treatment of removal of weeds by hand-pulling was introduced. It was also deemed necessary to find the effect of weeding under varying fertility of land for which the treatment of low and high fertility was included. Low fertility was represented by the exhausted field after a crop of Jowar (*Sorghum vulgare*). The chemical analysis of the soil at sowing-time of wheat showed 0·059 per cent. N, 0·131 per cent. total $P_2O_5$, and 0·988 per cent. $K_2O$ on the dry basis. High fertility was maintained by the addition of ammonium sulphate, superphosphate, and potassium sulphate at the rate of 50 lb. N, 80 lb. $P_2O_5$, and 60 lb. $K_2O$ per acre respectively. The fertilizer mixture was applied before sowing and

mixed during ploughings. A complex randomized-block design was followed with six treatments, viz. weeding with hand-hoe, weeding by hand-pulling, and no-weeding, each under low and high fertility with four replications, making in all twenty-four plots each of 1/80 acre (36 × 15 ft.). The variety of wheat was Pb 591.

As in previous years, the weeding treatments (by hand-hoe and hand-pulling) significantly increased the yield of grain per acre over no-weeding; but there was no significant difference between the two types

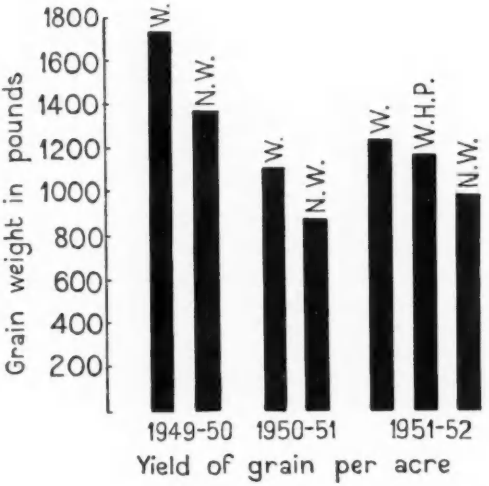



FIG. 1

FIGS. 1, 2, and 3 show the effect of weeding on wheat crop in different years. W = weeding by hand-hoe, W.H.P. = weeding by hand-pulling, N.W. = no-weeding.

TABLE 3. *Effect of Weeding on Number of Ear-bearing Tillers per Plant of Three Varieties of Wheat (1949–50)*

| *Treatments* | *No. of tillers* | *Critical difference* | *Increase over C 13,%* |
|---|---|---|---|
| Variety Local | 4·3 | at 5% 0·75 | 65·4 |
| ,, Pb 591 | 3·3 | at 1% 0·94 | 26·9 |
| ,, C 13 | 2·6 | .. | .. |

of weeding. The plants of the weeded crop also produced significantly more grain and more fertile tillers per plant. The superiority of the manured over non-manured plots was highly marked (Table 2, 1951–2). The response of the crop to the treatments of weeding was significantly (5 per cent.) greater for grain yield per acre under low fertility than that under high fertility (Table 4). The effect (overall) of weeding

by hand-hoe was marked by an increase over no-weeding of 27·8 per cent. in grain yield per acre, 86·0 per cent. in grain weight per plant, and 67·3 per cent. in number of ear-bearing tillers per plant.

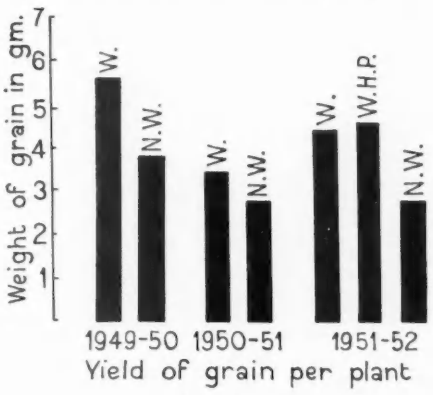



FIG. 2

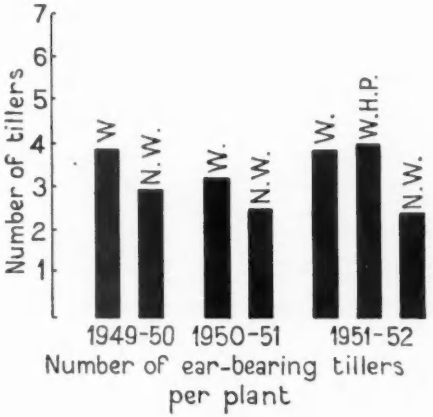



FIG. 3

*Discussion.*—The data of Tables 2, 3, and 4 show that the presence of weeds in the wheat-field led primarily to a decrease in the number of ear-bearing tillers and grain yield per plant, and as was to be expected the weeded plots, in all the trials conducted during the 3 years, showed a significant increase in the yield of wheat grain. The increase in grain yield per acre was due to increased grain weight per plant, which in turn was influenced by the increased number of ear-bearing tillers. The plants succeeded in producing more because they were free from competition with the associated weeds which had been weeded out.

Similar effects with cereal crops were observed by Pavlychenko and Harrington [3], Godel [4], Hidayatullah and Sen [5], and Mann and Barnes [6].

TABLE 4. *Interaction between Treatments of Weeding and Levels of Fertility*

| Treatments | Fertility levels: Grain yield lb./acre | | Fertility levels: Increase over no-weeding lb./acre | | Difference (4–5) | Critical difference |
|---|---|---|---|---|---|---|
| | Low | High | Low | High | | |
| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Weeding by hand-hoe | 710 | 1757 | 398 | 138 | 260 | 206 at 5% |
| Weeding by hand-pulling . . . | 620 | 1693 | 308 | 74 | 233 | 285 at 1% |
| No-weeding . . | 312 | 1618 | .. | .. | .. | .. |

The yield *per plant* showed a much greater percentage increase with weeding than yield *per acre*. Table 5 gives the density of the crop per acre calculated from the stand taken from random square-yard areas. It is seen that the density of the crop in the weeded plots was always less than that in the unweeded.

TABLE 5. *Density of Crop Plants (per acre) at the Time of Harvest*

| Treatments | Number of plants | | |
|---|---|---|---|
| | 1949–50 | 1950–1 | 1951–2 |
| Weeded . . . | 140,311 | 141,962 | 121,455 |
| Unweeded . . | 165,082 | 146,062 | 179,814 |

The variation in the average yield of grain per acre during the 3 years of experimentation was due to varying fertility of land under trial and the differences in stand of crop during different years. The effect of weeding was also influenced by the levels of fertility and the degree of weed infestation. The percentage increase in grain yield per plant of weeded crop over the unweeded was appreciably greater in the first year as compared with that of the second year (46·6 and 26·6 per cent. respectively). This is because the competition for plant-food nutrient in the second year was mild due to fewer weeds per unit area, whilst it was severe in the first year as the weed infestation was high (Table 1).

The influence of the levels of fertility was observed in the third year (1951–2) when prior to the experimental crop a fodder crop of Jowar was harvested to provide a basis for competition under low fertility. It is clear from the interaction Table 4 that the significant difference between the increases over no-weeding under low and high fertility was due to

proportionately greater response of the crop to the treatments of weeding (hand-hoe and hand-pulling) under low fertility than that under high fertility. The degree of weed infestation was of the same extent in both the treatments. It is thus clearly evident that the competition was more severe when plant nutrients were scarce. The extent to which the soil of the field was exhausted of fertility is clear from Table 2, the yield of grain under high fertility being 208·5 per cent. higher than that under low fertility. Mann and Barnes [6] and Blackman and Templeman [7] have also reported more competition between cereal crops and weeds under low fertility.

The comparison of the effect of the removal of weeds by hand-hoe and that by hand-pulling is clearly indicative of the fact that only the removal of the weeds from competition with the crop had a beneficial effect and not the creation of mulch. Similar were the findings of Call and Sewell [8]. No doubt considering the economics of the operation the removal of weeds by implements is advisable.

*Summary.*—The results of a 3-year experiment on the effect of weeding of wheat crop have been presented.

Weeding increased significantly the number of ear-bearing tillers per plant, the grain yield per plant and the grain yield per acre. The percentage increase of grain yield per acre of weeded crop over unweeded one was influenced by the degree of weed infestation. The response of crop to weeding was significantly greater under low fertility than under high fertility. The comparison of the effect of the removal of weeds by hand-hoe and that by hand-pulling showed clearly that only removal of the weeds from competition with the crop had the beneficial effect and not the mulch brought about by the hand-hoe used in weeding.

*Acknowledgement.*—My thanks are due to my Professor, Dr. N. K. Anant Rao, under whose guidance these investigations are being made.

## REFERENCES

1. G. H. Bates, Weed Control. Farmer and Stock-Breeder Ltd. London, 1st edition, 1948, p. 2.
2. F. Yates, The Design and Analysis of Factorial Experiments. Imperial Bureau of Soil Science, 1937.
3. T. K. Pavlychenko and J. B. Harrington, Canad. J. Res., 1934, **10**, 77–94.
4. G. L. Godel, Sci. Agric., 1935, **16**, 165–8.
5. S. Hidayatullah and S. Sen, Science and Culture, 1942, **7**, 365–7.
6. H. H. Mann and T. W. Barnes, Ann. Appl. Biol., 1945, **32**, 15–22.
7. G. E. Blackman and W. G. Templeman, J. Agric. Sci., 1938, **28**, 247–71.
8. L. E. Call and M. C. Sewell, J. Am. Soc. Agron., 1918, **10**, 35–44.

(*Received February 3, 1953*)

# GENETIC FACTORS AFFECTING WEIGHTS OF OSSIMI LAMBS

M. T. RAGAB, A. A. ASKER, AND M. R. KADI

(*Animal Breeding Department, Faculty of Agriculture, Giza, Egypt*)

EGYPTIAN sheep, which belong to the fat-tailed group, are bred for mutton production. In order to improve their productive ability in this respect, information concerning the effect of both environmental and hereditary factors on weights of sheep is needed.

The purpose of this work was to determine the heritability of birth, weaning, and marketing weights of Ossimi lambs. Such information is fundamental to breeding plans. The phenotypic as well as the genotypic correlations between weights at different ages were calculated, with the object of indicating to what extent genes responsible for birth weight operate in determining hereditary variation in subsequent weights of the same animal. Knowledge of this kind is undoubtedly required for making selection more efficient.

## *Data and Methods*

The data used in this work were taken from the weight records of Ossimi sheep kept by the Animal Breeding Department, Faculty of Agriculture, Giza, during the last 10 years. Records of 492, 436, and 413 animals were available for birth weight, weaning weight, and marketing weight of lambs respectively. Data on 218, 202, and 165 daughter-dam pairs were used in estimating the heritability of the three weights in the same order.

Lambs were usually weighed within 12 hours of their birth, then every 2 weeks until 6 months of age (i.e. marketing age). Weaning took place when lambs were 4 months old. No culling was practised before marketing age, except for death losses. Selection was performed for increasing twinning and improving rate of growth.

Heritability of weights was estimated using the intra-sire regression of daughters on dams [1]. The formula developed by Lerner [2] was used for correcting heritability estimates for inbreeding, since the flock was inbred [3]. The same authors [4] have shown that type of birth, sex of lambs, and age of the dam affect significantly the weight of lambs at different ages. Therefore, heritability estimates were worked out after correcting for these factors.

Phenotypic correlations between possible combinations were calculated for the three weights [5]. The method suggested by Hazel [6] was utilized in studying the genetic correlations between weights. This method correlates the phenotypic expression of one character in one animal with the phenotypic expression of another character in a closely related animal. Hazel's formula was expressed in these data in terms of regressions.

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953.]

### *Results and Discussion*

*Heritability of birth, weaning, and marketing weights.*—Heritability estimates, obtained after adjusting the data for environmental factors for the three weights studied are shown in Table 1.

TABLE 1. *Heritability of Weights in Ossimi Sheep*

| *Weight* | *No. of sires* | *Daughter-dam pairs* | *Heritability* |
|---|---|---|---|
| Birth weight . . . . | 7 | 218 | 0·34±0·13 |
| Weaning weight . . . . | 6 | 202 | 0·10±0·14 |
| Marketing weight . . . . | 7 | 165 | 0·29±0·20 |

The heritability estimates obtained here were 0·34, 0·10, and 0·29 for birth, weaning, and marketing weights respectively. It should be noted that there were no significant differences between the three estimates.

Chapman and Lush [7], have reported that only 25–30 per cent. of the variation in birth weight of lambs was hereditary, which agrees with our results. Ensminger *et al.* [8] found the heritability of birth weight in Shropshire and Southdown sheep to range between 8 and 40 per cent., while Nelson and Venkatachalam [9] reported an estimate of 61 per cent.

The heritability estimate for weaning weight in this investigation was 10 per cent. This estimate is close to that reported by Hazel and Terrill [10] on Columbia, Corriedale, and Targhee sheep (17 per cent.), while it is lower than that obtained by the same authors [11] on Rambouillet sheep, and that reported by Nelson and Venkatachalam [9] and Karam *et al.* [12].

Most of the investigators mentioned above concluded that the heritability of weaning weight is lower than that of birth weight. This result may be attributed to the fact that environmental factors play a greater role in weaning weight than in birth weight. Although it was possible to adjust the data for some known environmental factors which affect weights, it should be noted that unknown factors for which correction could not be made played an important part in the development of body weight up to weaning age. The coefficients of variability for birth and weaning weight in these data were 19 per cent. for the former and 25 per cent. for the latter. Blunn [13] came to the same conclusion after analysing the data of birth weight and weaning weight in Navajo sheep.

The heritability estimate for marketing weight came to 29 per cent. It is not possible to compare this estimate with those of other workers, since age of marketing varies in the different flocks as well as in the different localities.

*Phenotypic correlations between weights.*—Table 2 shows the phenotypic correlations between the three weights studied.

Our results confirm the work of other investigators [14, 15, 16], who found that significant correlations exist between the birth weight of lambs and weights at different ages. The correlation coefficient obtained in this study between weaning and marketing weights is in close agreement

with that reported by Johansson [17], who found a correlation coefficient of 0·857 between weights of lambs at 3 and 5 months of age. The same author found that there was no significant correlation between the birth weight of lambs and their weight at 5 months.

TABLE 2. *Phenotypic Correlations between Weights*

| *Weights correlated* | *No. of animals* | *Correlation coefficient r* |
|---|---|---|
| Birth and weaning weight . . . . | 492 | 0·594† |
| Birth and marketing weight . . . . | 436 | 0·480† |
| Weaning and marketing weight . . . | 413 | 0·860† |

† Sig. at P = 0·01.

It is indicated in Table 2 that the correlation coefficients between successive weights were higher than those between non-successive. This is due to the fact that environmental variations play a great role in the individual correlation, and consequently the shorter the period between weights studied, the less is the effect of environmental factors.

*Genetic correlations between weights.*—The genetic correlations between weights of lambs at different ages are presented in Table 3. The first estimate (1·043) is over 1·00, the upper limit for a correlation coefficient, but the difference is not statistically significant.

TABLE 3. *Genetic Correlations between Weights*

| *Weights correlated* | *Daughter-dam pairs* | *Genetic correlation r* |
|---|---|---|
| Birth weight and weaning weight . . | 186 | 1·043 |
| Birth weight and marketing weight . . | 147 | 0·819 |
| Weaning weight and marketing weight . | 139 | 0·959 |

It is evident from Table 3 that the genetic correlations between the possible combinations for the three weights studied were very high—close to unity. In other words, the three weights are controlled by the same set of genes. It should be noted that the number of daughter-dam pairs used in studying the genetic correlations was limited and the genetic correlation estimates should consequently have high standard errors. In fact these errors were around 1·00. Morley [18] gave an estimate of 2,500 for the number of parent-offspring pairs required for a reliable estimate of a genetic correlation of 0·40, where the heritability of each character being correlated was also 0·40 and the standard error of the correlation was taken to be approximately one-fourth of its value.

It is interesting to note that the genetic correlations obtained between different weights were higher than the corresponding phenotypic correlations (Tables 2 and 3). This can be attributed to the fact that phenotypic correlations contain an environmental component as well as the genetic one, whilst genetic correlations measure only the additive effect

of genes that affect two characteristics in the same animal, plus some of their epistatic effect, since these alone contribute to the likeness between daughter and dam which was the basis of the estimations.

*Application of results.*—This study has shown that the heritabilities of birth, weaning, and marketing weights do not differ significantly. Since records for birth weight can be obtained at an earlier stage of life it is advisable to use these records for selection. Although the number of daughter-dam pairs used for estimating the genetic correlations between different weights was small, their value cannot be overlooked. Undoubtedly, if more data were available and the same values of genetic correlations were obtained, the breeder could safely depend upon birth-weight records in planning his breeding schemes for improving weight in sheep. This is due to the fact that the genes responsible for birth weight are also responsible for weaning and marketing weights. This will enable breeders to benefit by early culling of undesired animals.

Since heritability of birth weight is only 34 per cent., breeders are not advised to use phenotypic selection alone as a basis for improving weights in sheep. Information on pedigrees, collateral relatives, and that obtained from progeny testing should be utilized in selecting animals for breeding purposes.

## *Summary*

Data on 218, 202, and 165 Ossimi daughter-dam pairs were used to study the heritability of birth weight, weaning weight, and marketing weight of lambs. Phenotypic and genetic correlations between weights of lambs at different ages were also calculated. Records used in this analysis were collected by the Animal Breeding Department, Faculty of Agriculture, Giza, and covered a period of 10 years.

The heritability of birth weight, weaning weight, and marketing weight, on data adjusted for sex of the lamb, type of birth, age of the dam, and inbreeding of lambs were 34, 10, and 29 per cent. respectively.

Phenotypic correlations between birth weight and weaning weight, birth weight and marketing weight, and weaning weight and marketing weight were found to be 0·594, 0·480, and 0·860 in the same order. This study showed that the genetic correlation between birth weight and weaning weight was 1·043, that between birth weight and marketing weight was 0·819, and that between weaning and marketing weight was 0·959.

## REFERENCES

1. J. L. Lush, Heritability of Quantitative Characters in Farm Animals. Proc. 8th Inter. Cong. of Genetics, Stockholm, 1948, p. 356.
2. I. M. Lerner, Population Genetics and Animal Improvement. Cambridge University Press, 1950.
3. M. T. Ragab, A. A. Asker, and S. F. Shimy, A Genetic Analysis of Two Flocks of Egyptian Sheep. Bull. No. 12, Faculty of Agric., Giza, Egypt, 1952.
4. A. A. Asker, M. T. Ragab, and M. R. Kadi, The Influence of Some Environmental Factors Affecting Weight of Ossimi and Rahmani Sheep. Bull. No. 19, Faculty of Agric., Giza, Egypt, 1952.
5. G. W. Snedecor, Statistical Methods. Iowa State College Press, 1948.
6. L. N. Hazel, Genetics, 1943, **28**, 476.
7. A. B. Chapman and J. L. Lush, J. Hered., 1932, **23**, 473.

XUM

8. M. E. ENSMINGER, R. W. PHILLIPS, R. G. SCHOTT, and C. H. PARSONS, J. Anim. Sci., 1945, **2,** 157.
9. R. H. NELSON and G. VENKATACHALAM, Ibid., 1949, **8,** 605.
10. L. N. HAZEL and C. E. TERRIL, Ibid., 1945, **4,** 437.
11. —— —— Ibid., 1949, **5,** 371.
12. H. A. KARAM, A. B. CHAPMAN, and A. L. POPE, Ibid., 1953, **12,** 148.
13. C. T. BLUNN, Ibid., 1944, **3,** 41.
14. J. A. GLEMBOCKII and G. V. BOGALJUBOUA, The Relation of the Birth Weight of Lambs to their Subsequent Growth. Anim. Breeding Abst., 1940, **10,** 237.
15. C. M. KINCAID, J. Anim. Sci., 1943, **2,** 152.
16. G. DUNLOP, Selection of Ewe Lambs for Hill Flocks, Anim. Breeding Abst., 1947, **15,** 253.
17. I. JOHANSSON, Some Results from Recording Lamb Production of Ewes by the Swedish Sheep Breeding Association. Ibid., 1937, **8,** 44.
18. F. H. W. MORLEY, Selection For Economic Characters in Merino Sheep. Ph.D. thesis, 1950, Iowa State College, Ames, Iowa, U.S.A.

*(Received May 13, 1953)*

# OBSERVATIONS ON THE ECOLOGY OF *STOEBE VULGARIS* LEVYNS

E. R. HATTINGH

(*African Explosives and Chemical Industries, Limited, Johannesburg*)

WITH PLATE 11

IN grassland studies at Frankenwald, the Field Research Station of the University of the Witwatersrand, Johannesburg, considerable attention has been paid to the ecology of *Stoebe vulgaris* Levyns (*Slangbos*) over the past 20 years, in a study of the conditions promoting its establishment and spread in natural grassland. A detailed anatomical study of the plant was made by Gillman [1]; Cohen [2, 3, 4] undertook a comprehensive aut-ecological study, and van Rensburg [5] reported on its eradication.

During the 13 years since the publication of these papers Stoebe has continued to spread at an alarming rate in the grassland regions and it presents a serious problem in grazing management. During this period no important contribution to its ecology or control has been made and an object of this paper is to stimulate further research into the problem.

In previous papers on Stoebe [2, 5] it was suggested that overgrazing leads to its appearance, and this view is widely held in this country. As Stoebe is very frequently found, however, on areas which are seldom grazed at all, the view is advanced in this paper that Stoebe encroachment is not due so much to overgrazing as it is to the poor fertility status of abandoned lands.

*Description of the plant.—Stoebe vulgaris* is a woody, unpalatable shrub growing to about 2½ ft. in height. The mature plant develops a gnarled, thickened rootstock which gives rise to several stems covering an area of 10 or more square feet of bare soil. The lower stems bear many dormant buds capable of shooting after fire, trampling, mowing, &c. The leaves are ericoid in appearance and are about $\frac{1}{16}$ in. long, arranged in clusters. Root transects have shown that the root is capable of extending to a depth of 5 ft.

Vegetative reproduction does not occur normally, the plant depending upon its excellent seed production for reproduction. During winter the plant becomes brown and dry but in spring it draws upon its root reserves and assumes a green colour; in addition, new basal shoots may appear. Flowering occurs in the autumn months simultaneously with the climax grass *Trachypogon plumosus*, and the seeds ripen from May to June. Seed distribution occurs by wind, violent gusts and whirlwinds serving in its dispersal. A viability of 40 per cent. may be expected under optimum conditions [2] and a high soil moisture is required for germination.

## *Distribution of* Stoebe vulgaris

Stoebe is chiefly a South African genus, some thirty-four species being listed by Levyns [6], of which two occur in Madagascar, one in Reunion,

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953].

and one in central Africa, the largest number of species being found in the south-western corner of the Cape Province. *Stoebe vulgaris*, which is apparently the only aggressive member of the genus, does not occur in the south-western Cape but is recorded from the Transvaal, Orange Free State, eastern Cape, Natal, and Rhodesia; it presents a problem only in certain portions of the Highveld grassland formation (Fig. 1).

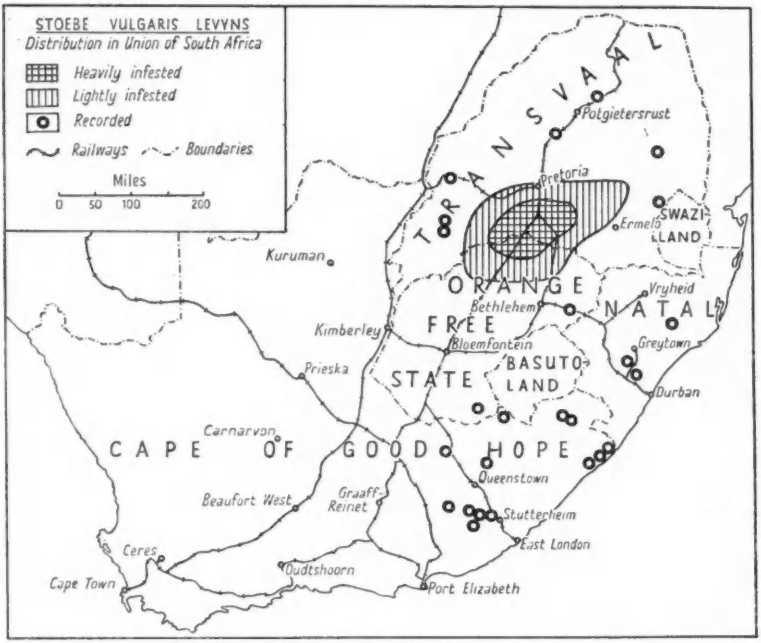



FIG. 1

*Distribution within the grassland formation.*—Within the grassland formation certain factors play a deciding role in governing its distribution. Decreasing rainfall seems to limit its spread to the west, and it has been noted that it flourishes best on a summer rainfall of 25–30 in. per annum.

*Influence of soil type.*—Stoebe is almost entirely confined to light sandy soils, being virtually absent on heavy soils, even where these adjoin heavily infested light soils, as in the country between Reitz and Villiers. It thus does not occur on the Turf Themeda veld of the Highveld where heavy soils predominate, but is prevalent in the Bankenveld and the sandy Cymbopogon-Themeda veld.

With the information drawn from reconnaissance by the author and his colleagues; from a questionnaire submitted to officials of the Union Department of Agriculture; and from records kindly submitted by Acocks

of the Botanical Survey Section of the Department of Agriculture, the known distribution of *Stoebe vulgaris* is shown on the accompanying map (Fig. 1). It will be observed that Stoebe finds its highest concentration in the southern Transvaal and northern Free State, particularly in the watershed of the Vaal river. Of this area it is estimated that 2 million acres are infested.

### *Role in Succession*

(i) *Ruderal stage.*—Stoebe has seldom if ever been found to act as a pioneer. It may be found in abundance in grassland along road-sides, but has not been observed as a pioneer on bare ground. Its appearance along road-sides may be due to seed dispersal by sheep and by wagons carrying hay and bedding.

(ii) *Secondary succession on old fallows.*—Stoebe has been found to occur mainly in secondary succession on old fallows on light sandy soils, not only at Frankenwald but widely in the infested area in the grassland regions. It has not been observed to appear before the Eragrostis stage nor within the first 5 years after fallowing. It is usually found in association with Eragrostis spp. and *Hyparrhenia hirta*. It is thought that at this stage the available nitrogen content of the soil is at a very low level.

(iii) *Climax veld.*—Stoebe is not confined to the successional stages on old fallows, but may also be found in climax *Trachypogon plumosus* veld. It may also be abundant on rocky hill-side slopes and unploughable areas.

Stoebe encroachment is generally not associated with moist conditions or a high water table, but on the contrary is usually found on dry sites.

### *Effect of Management*

*Overgrazing.*—Little evidence can be found at Frankenwald that overgrazing is a direct cause of Stoebe encroachment. In experiment U 3 laid out in 1937 and described by van Rensburg in 1940 [5], the effect of overgrazing on Stoebe is demonstrated in a remarkable manner. In those plots heavily grazed twice weekly by cattle, complete eradication of Stoebe has been achieved and a good grass cover established. It should be stressed, however, that a considerable amount of fertility may have been transferred to these plots by the animals from outside the experiment, and the role of increased fertility in the eradication of Stoebe should not be overlooked. In Plate 11, Figs. 2 and 3 show the heavily grazed plots at the initiation of the experiment and 16 years later.

*Trampling.*—This is not thought to be the cause of Stoebe encroachment, from evidence gained from the grazing and trampling experiments at Frankenwald.

*Mowing.*—Mowing twice during the growing season does not make any appreciable difference to the abundance of Stoebe, although it allows the grass to compete more vigorously.

*Burning.*—Burning during the winter months has little effect on the plant, which is very resistant to fire. There is evidence, however, from experiments at Frankenwald that burning during the spring and summer months will prevent the establishment of Stoebe seedlings, and therefore the encroachment of this plant.

*Protection.*—Complete protection of old fallows provides ideal conditions for the increase of Stoebe. Unmown or unburnt Stoebe rapidly shades out the grass constituents of the flora. Increases in abundance on fallows 15 to 20 years old are frequently observed and it is only after 15 years of protection that any decline in vigour is noted. Resting the veld, therefore, is not a practical means of eradication. Plate 11, Fig. 4, shows a plot protected for 16 years.

*Grazing.*—Stoebe appears to be capable of infesting a pasture under conditions of reasonable veld management, including rotational grazing and mowing. Apart from the soil fertility effects, grazing does not appear to influence its spread.

### *Effect of Soil Fertility*

The hypothesis is advanced that the encroachment of Stoebe is largely due to lowered soil fertility.

A vigorous grassland should itself keep Stoebe from encroaching, but it is evident that some change in the habitat has occurred providing ideal conditions for encroachment. Where it occurs in abundance in the Highveld grassland regions it is usually on land once under the plough. It is suggested that the abundance of Stoebe on abandoned lands results from the breakdown of these soils under cultivation and monoculture, with a consequent drop in soil fertility. This lowered fertility may possibly be due to actual removal of top-soil by erosion, but also to the breakdown of organic matter under cultivation with the resulting loss of nitrogen. The weak grass sward which appears on such lands is unable to compete successfully with the Stoebe which can apparently thrive under conditions of poor fertility.

The question of fertility under grazing is not as straightforward as under actual cropping conditions. However, a considerable amount of fertility is removed from a pasture by the grazing animal, especially if the animals are kraaled at night and if they are watered off the pasture. The actual removal of top-soil by erosion under grazing conditions also accounts for a decrease in fertility.

The adding of nitrogen to an old fallow under *Cynodon dactylon* and its effect on subsequent Stoebe encroachment have been studied. In an experiment carried out by Meredith [7] the effect of heavy nitrogen applications to Cynodon (222 lb. nitrogen per acre for 4 years) was to keep Stoebe out for several years longer than on unfertilized plots.

However, over a 6-year period the application of an average of 31·5 lb. nitrogen per acre to veld under a system of grazing and mowing has not served to reduce the infestation of Stoebe.

Further evidence of the relationship between Stoebe and fertility is noted from the effect of the application of sewage night-soil to Stoebe infested grassveld on the Heidelberg townlands. Where the sewage was applied the Stoebe has completely disappeared and has been replaced by a vigorous grass community.

### *Prevention of the Spread of Stoebe*

Although it is possible to eradicate Stoebe from pastures by means of

FIG. 2. *Plot No. 1.* On 5.6.1938, at the initiation of the heavy grazing treatment

FIG. 3. *Plot No. 1.* In April 1952, after 14 years of heavy grazing

FIG. 4. *Plot No. 5.* Control. Protected from grazing since 1938

the selective herbicides, yet there is no answer to the problem of possible reinfestation. A technique of management is needed which will ensure that further infestation does not occur. Burning during early summer may be a means of preventing seedling establishment, but is destructive to the grass cover and is generally undesirable. Altona [8] has described a method whereby old fallows can be brought up to peak production by means of the application of nitrogenous fertilizers. If we are to keep our pastures Stoebe-free and in maximum production, the use of nitrogen to increase the fertility of old fallows appears to be a necessity. Returning a cropped soil to a temporary ley which receives adequate nitrogen applications has its obvious advantages over the wasteful system of abandoning lands and it is suggested that this practice may prevent further infestation.

*Acknowledgements.*—The writer wishes to thank the many members of the Department of Agriculture who replied to the questionnaire and also Dr. R. L. Davidson, Assistant Director of the Frankenwald Field Research Station, for guidance and providing access to the experimental records. Thanks are also due to Dr. Meredith, Manager, Agricultural Field Research Department, African Explosives and Chemical Industries, Limited, Johannesburg, and to the writer's colleagues in this department for help in the reconnaissance.

*Summary.*—The problem of the encroachment of *Stoebe vulgaris* is defined and its distribution in the Union of South Africa is mapped. The concept that the encroachment of this plant is due more to the exhaustion of soil fertility, and subsequent abandonment of lands, than to overgrazing is advanced. It is suggested that the rehabilitation of old lands by means of nitrogen applications either to the existing grasses, once the removal of Stoebe has taken place, or to an artificially planted grass ley may be the key to preventing further infestation.

## REFERENCES

1. H. GILLMAN, *Stoebe cinerea*. M.Sc. thesis (unpublished), Witwatersrand University, 1934.
2. C. COHEN, J. South African Botany, 1935, **1**, 171.
3. ——, South African J. Sci., 1936, **33**, 351.
4. ——, J. South African Botany, 1940, **6**, 79.
5. H. J. VAN RENSBURG, South African J. Sci. 1940, **37**, 175.
6. M. R. LEVYNS, J. South African Botany, 1937, **3**, 1.
7. D. B. D. MEREDITH, The effect of fertilizers on grasses in certain areas of South Africa with special reference to nitrogen. D.Sc. thesis, Witwatersrand University, 1947.
8. R. E. ALTONA, Soil rehabilitation demonstrated at Frankenwald. The Farmer's Weekly, 1953 (27 May), p. 55.

(*Received August 3, 1953*)

XUM

# BACK-CROSSING OF WHEAT FOR RESISTANCE TO BUNT IN SOUTH AUSTRALIA

A. T. PUGSLEY

(*Waite Agricultural Research Institute, University of Adelaide, South Australia*)

WITH PLATE 12

In an earlier publication [1] an outline was given of a breeding programme for the production of bunt-resistant varieties of wheat for South Australia.

In discussing the range of parental material available for use in such a programme reference was made to the high level of resistance found in the tetraploid wheat Doubbi and of its incorporation in *vulgare*-like derivatives from crosses between that variety and Ranee.

Preliminary work which had indicated that a major gene for resistance was operative has now been confirmed and a breeding programme based on the back-cross technique has been carried through to completion with the production of three new varieties. This breeding programme is an extension of that already described [2] for the incorporation of stem-rust resistance in South Australian wheat varieties.

## *Materials and Methods*

In 1941 Ranee was crossed with the tetraploid variety Doubbi, the latter being used as the male parent. The $F_1$ was back-crossed to Ranee and two subsequent selfings provided sixty $F_3$ lines which, after inoculation with a mixture of 'races'[1] of *Tilletia caries* and *T. foetida*, were sown in the field in 1944.

Several families were completely free of bunt and from two—6189 and 6246—single-plant selections of *vulgare*-like types were made. One selection, hereafter designated R.D.R. 6189, was used as the non-recurrent parent in each of three series of crosses and back-crosses. Insignia (and later a stem-rust resistant derivative Insignia 49), Javelin 48, and Ridley 48 were used as the recurrent parents respectively. Each of these had previously been shown to be susceptible to five Australian 'races' of bunt. The origins of each of the recurrent parents have been reported upon elsewhere [2].

A second single-plant selection, R.D.R. 6246, has been maintained although it has not been used in further crosses.

The bunt inoculum used throughout the tests has varied from experiment to experiment but was always a single 'race' of one of the following: 'races' T. 5 and T. 2 of *T. caries* and 'races' L. 1, L. 14, and L. 3 of *T. foetida*. The pathogenic characteristics of these 'races' and the methods of inoculating seed have been outlined previously [1].

Doubbi has remained bunt-free when inoculated with each of the five 'races'. The several back-crossed derivatives have also been resistant

[1] The use of 'race' as a descriptive term for plant pathogens has been discussed in a recent paper [3].

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953.]

to each 'race' but variations in the extent of expression of the incorporated Doubbi resistance have been observed, such variations being dependent in part on the 'race' of bunt used, in part on the genotype of the newly derived variety, and in part on the environmental conditions prevailing during the test. Resistance has been best expressed in Ridley derivatives and less well expressed in Insignia and Javelin derivatives. Resistance of a higher order has been found to 'races' L. 1 and T. 5 than to 'race' T 2.

Studies on the inheritance of resistance have been conducted simultaneously with the breeding work, the results of which are set out in the following section.

Previous genetic studies both in Adelaide and elsewhere, notably in California, have made use of infection percentages based on the proportion of infected plants per row, a plant being classed as susceptible if bunt balls could be found in any one of the ears. However, in the present studies, such methods have not always proved satisfactory, for, on certain occasions, homozygous-resistant rows have been found to contain plants with partially bunted ears or with occasional grains partially bunted (Plate 12). Whenever partially bunted grains have been germinated, the resultant plants have always been quite healthy, confirming the fact that the parent plants were in fact genotypically resistant.

The partial bunting of ears was commonly observed in 1952 and in that year additional readings were made, when infection percentages were based on the proportion of plants which had at least one completely bunted ear. This provided a more ready assessment of segregating ratios.

## *Results*

(*a*) *Insignia series of crosses*.—During the summer of 1944 an $F_3$ selection of (Ranee × Doubbi)$^1$ × Ranee, (R.D.R. 6189), was crossed to Insignia, and in 1946 thirty-one $F_3$ families were tested using 'race' L. 3 as inoculum. Although infection percentages were not assessed, seven of the thirty-one families were free of bunt. $F_4$ selections from each of the seven families were tested against the same 'race' in 1947 and in each case their resistance was confirmed.

One such $F_4$ selection was crossed to Insignia 49, and by 1949 twenty $F_3$ families of (R.D.R. 6189 × Insignia)$^4$ × Insignia 49 together with a single random $F_4$ selection from each were available for testing with 'race' L. 1. The results of this test are set out in Table 1.

These results suggest that three $F_3$ families were homozygous resistant, five were homozygous susceptible, and twelve were segregating for resistance. One of the resistant $F_3$ selections (1760–3) was carried on for testing against four other bunt 'races' in 1951. This selection, now in $F_5$, was completely free from bunt when inoculated with 'races' T. 5, L. 14, and L. 3, and 11 per cent. infection was recorded for 'race' T. 2.

Prior to conducting the above-mentioned tests a number of plants from $F_3$ families were back-crossed a second time to Insignia 49. When the results of the 1949 test became available, the back-cross stemming from the resistant 1760–3 was selected for further testing, the remainder being discarded.

TABLE 1. *Percentage Bunt Infection of $F_3$ and $F_4$ Families from the Cross (R.D.R. 6189 × Insignia)$^4$ × Insignia 49. 'Race' L. 1, 1949*

| $F_3$ family | Derived $F_4$ selection | $F_3$ family | Derived $F_4$ selection |
|---|---|---|---|
| 5 (1760–3) | 0 | 25 | 65 |
| 15 | 0 | 55 | 15 |
| 15 | 15 | 35 | 40 |
| 65 | 30 | 65 | 20 |
| 50 | 10 | 20 | 75 |
| 35 | 80 | 75 | 80 |
| 50 | 45 | 80 | 95 |
| 50 | 85 | 80 | 90 |
| 30 | 50 | 90 | 70 |
| 30 | 10 | 85 | 90 |

Thus, in the winter of 1950 eighty-four $F_3$ families of [(R.D.R. 6189 × Insignia)$^4$ × Insignia 49]$^3$ × Insignia 49 were tested using 'race' L. 1 as inoculum. The results of this test are set out in Table 2.

TABLE 2. *Frequency Distribution of Bunt Infection of the Parents, the $F_2$ and the $F_3$ of the Cross [(R.D.R. 6189 × Insignia)$^4$ × Insignia 49]$^3$ × Insignia 49. 'Race' L. 1, 1950*

| Parent or cross | Distribution of rows having a bunt infection (%) of | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0–10 | 11–20 | 21–30 | 31–40 | 41–50 | 51–60 | 61–70 | 71–80 | 81–90 |
| Insignia 49 | .. | .. | .. | .. | .. | .. | 1 | 1 | .. |
| (R.D.R. 6189 × Insignia)$^4$ × Insignia 49 | 2 | 1 | .. | .. | .. | .. | .. | .. | .. |
| [(R.D.R. 6189 × Insignia)$^4$ × Insignia 49]$^3$ × Insignia 49, $F_2$ | .. | .. | .. | .. | 1 | .. | 1 | .. | .. |
| ,, ,, $F_3$ | 10 | 1 | 12 | 8 | 7 | 15 | 13 | 9 | 9 |

Although the data of Table 2 may not reveal a very clear segregation of $F_3$ families into three classes, approximately one-quarter had less than 31 per cent. bunt, one-quarter had more than 70 per cent. bunt, and one-half had infection ratings ranging from 31 to 70 per cent. Plants from six of the most resistant lines were crossed back to Insignia 49 and at the same time each was carried forward to the $F_4$ generation where their resistance to 'race' T. 2 was demonstrated in 1951. In 1952 each selection, now in $F_5$, was shown to be resistant to 'races' L. 1 and T. 5.

By 1952 one group of $F_3$ families from {[(R.D.R. 6189 × Insignia)$^4$ × Insignia 49]$^3$ × Insignia 49}$^3$ × Insignia 49 were available for testing against 'race' L. 1. On this occasion seven families gave infection figures

ranging from 5 to 21 per cent. while the corresponding figures for the remaining fourteen families ranged from 31 to 67 per cent. As already mentioned, additional readings were made in 1952 using a different method of assessing susceptibility. It is of interest to note that although completely bunted ears were common in the susceptible group of fourteen families, no completely bunted ears were found in the seven resistant families. Furthermore, in a duplicate sowing, inoculated with 'race' L. 14, during the late winter of 1952, the seven resistant families were completely free of bunt and confirmed the view that resistance to 'races' L. 1 and L. 14 had a common basis.

Evidence for the recovery of the yielding qualities of the recurrent parent is limited to a single yield test where R.D.R. 6189 × Insignia × Insignia 49 × Insignia 49 did not significantly differ in yield from Insignia 49.

Additional yield trials will be necessary before this material is made available for general cultivation.

(*b*) *Javelin series of crosses.*—During the summer of 1945 an $F_5$ selection of Ranee × Doubbi × Ranee (6189) was crossed to Javelin 48, and in 1947 forty-seven $F_3$ families were tested after inoculation with 'race' L. 1. Although the degree of infection was low (40 per cent. for Javelin 48), thirteen families, or approximately one-quarter, were classed as being as susceptible as Javelin 48. However, it was not possible to separate with any degree of confidence a homozygous-resistant group from the remaining heterozygotes. Only one family was free of bunt, and after confirming this resistance in the following year a first back-cross of an $F_4$ plant was made to Javelin 48.

Twenty-two $F_3$ families of (R.D.R. 6189 × Javelin 48)$^4$ × Javelin 48 were tested against 'race' T. 5 in 1949. Seeding, delayed until mid-August, resulted in a poor establishment and prevented a satisfactory analysis of the segregation. Eight families had less than 5 per cent. of the plants infected, and again a plant from a bunt-free row was selected for the second back-cross to Javelin 48. Subsequently the resistance of this selection to 'races' L. 1 and T. 2 was confirmed in 1950 and 1951.

$F_3$ families of [(R.D.R. 6189 × Javelin 48)$^4$ × Javelin 48]$^3$ × Javelin 48 were tested against 'race' T. 2 in 1951 but a generally low degree of infection made classification difficult. Remnant seed of fifty-seven families was tested against 'race' L. 1 in 1952, the results being set out in Table 3.

These results show that thirteen families had less than 21 per cent. bunt, with the remaining families showing no clear evidence of a discontinuity. However, when a re-examination of this material was made, using the criterion that susceptibility requires that complete ears be bunted, then twelve of the thirteen most resistant rows were homozygous resistant and the remaining one was classed in the segregating group. The segregation of forty-five susceptible and segregating families to twelve resistant is in agreement with a monofactorial segregation at a $P > 0{\cdot}3$ level of probability. Four resistant selections from the 1951 test were carried to $F_5$ and retested in 1952 with 'races' L. 1, L. 14, T. 2, and T. 5 and in each case infection was restricted to a partial smutting

of ears. Yield trials with these four selections indicated that the yielding properties of Javelin 48 had been recovered and when confirmation is secured they will provide stock seed for a new bunt-resistant strain of Javelin 48.

TABLE 3. *Frequency Distribution of Bunt Infection of the Parents and the $F_3$ of the Cross [(R.D.R. 6189 × Javelin 48)$^4$ × Javelin 48]$^3$ × Javelin 48. 'Race' L. 1, 1952*

| *Parent or cross* | *Distribution of rows having a bunt infection (%) of* | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | *0–10* | *11–20* | *21–30* | *31–40* | *41–50* | *51–60* | *61–70* | *71–80* |
| Javelin 48 | .. | .. | .. | .. | 1 | 1 | 1 | .. |
| (R.D.R. 6189 × Javelin 48)$^4$ × Javelin 48 | 1 | 2 | .. | .. | .. | .. | .. | .. |
| [(R.D.R. 6189 × Javelin 48)$^4$ × Javelin 48]$^3$ × Javelin 48, $F_3$ | 8 | 5 | 2 | 14 | 19 | 4 | 1 | 4 |

(*c*) *Ridley series of crosses.*—During the summer of 1945 an $F_5$ selection of Ranee × Doubbi × Ranee (6189) was crossed to Ridley 48 and in 1947 thirty-three $F_3$ families were tested after inoculation with 'race' L. 1. A low degree of infection did not permit the analysis of the resulting segregation, but ten families were free of bunt. A selection from one of these families was carried to $F_4$ and the first back-cross was made during the summer of 1947. The same selection was shown to be resistant to 'races' L. 1 and T. 5 in 1948.

Instead of carrying the first back-cross to the $F_3$, the second back-cross was made to the $F_1$ of (R.D.R. 6189 × Ridley 48)$^4$ × Ridley 48 in 1948, and $F_3$ families were available for testing against 'race' T. 5 in 1949. Ten groups of families were represented in this test and, on the expectation of a single gene segregation, one-half of such groups were expected to contain only homozygous-susceptible families while the remaining half were expected to contain a proportion of homozygous-resistant rows. This expectation was realized when six groups consisted of susceptible families alone and each of the remaining four groups contained bunt-free families.

The third back-cross was made to a single plant of a bunt-free family of {[(R.D.R. 6189 × Ridley 48)$^4$ × Ridley 48]$^1$ × Ridley 48}$^3$ and $F_3$ segregations were studied in 1952 after inoculation with 'race' L. 1. The resistant parent of the third back-cross has been maintained and its resistance to 'races' L. 1, L. 3, T. 2, and T. 5 was demonstrated in 1952.

Of the forty $F_3$ families of the third back-cross tested in 1952 seven were free of bunt and seven, although containing some smutted plants, showed only a partial smutting of the ears and were accordingly classed as homozygous resistant. The observed segregation of twenty-six susceptible and segregating rows and fourteen resistant rows is in agreement with an expected 3:1 ratio at a $P > 0{\cdot}1$ level of probability.

Yield trials with four selections of the third back-cross have indicated the recovery of the yielding properties of Ridley 48 and seed stocks of this selection are being increased for further testing.

*Discussion*

In considering the results arising from the studies of the past twelve years it is clear that the bunt resistance transferred from Doubbi may quite readily be incorporated in commercial varieties by utilizing the back-cross technique.

Taken as a whole the evidence has indicated that a single gene is operative against all five Australian 'races' of bunt. Although not conclusive, the data suggest that resistance is recessive to susceptibility. One characteristic feature of this resistance is that of variability of its expression, particularly the not uncommon occurrence of partially bunted ears and grains.

Although intercrosses have not been made with other varieties carrying different genes for resistance, the evidence that follows suggests that the Doubbi resistance is different from that previously described by Briggs and his associates. If this is confirmed it would be appropriate to designate the gene from Doubbi as the 'd' gene.

Briggs and Holton [4] have presented data on the reactions of twelve varieties of wheat each containing, singly or in combination, four major and two minor genes for resistance to twenty-five 'races' of *T. caries* and *T. foetida*. In a private communication Holton [5] reported on the resistance of (R.D.R. 6189 × Insignia) to these same 'races'. Seeded in the spring of 1951 this selection was resistant to all the U.S. strains with the exception of L. 7, a result confirmed by further tests in 1952. The behaviour of this selection is clearly different from those varieties containing the single genes M, H, R, T, X, and Y respectively. Varieties carrying three other minor genes U, V, and W reported upon by Baker [6] and Smeltzer [7] give infection figures for T. 1 much higher than that found for (R.D.R. 6189 × Insignia).

At Adelaide comparative studies have been restricted to material containing the M, H, T, and 'd' genes and a characteristic but different pattern of behaviour towards the five Australian 'races' of *T. caries* and *T. foetida* has been established for each.

This differential behaviour to physiological 'races' as shown by susceptibility ratings is one manifestation of the inherent differences between varieties carrying different genes for resistance. Other manifestations which have been noted by overseas workers involve modification of ear type, a dwarfing of tillers, a variability in susceptibility associated with soil temperatures, and variations in the proportion of tillers which develop bunt lesions.

The experience of the author has been that both back-cross derivatives and the original parental varieties containing either the M or H gene, when infected, usually show a much higher proportion of infected tillers per plant than corresponding material containing the T gene. In fact two back-cross derivatives of Ranee, one containing the H gene and the other the T gene, may readily be distinguished from each other on this

basis, the latter characteristically showing 'late tiller infection'. Thus, for each of the derived varieties discussed in this paper it is possible to identify the associated 'd' gene for resistance by the characteristic partial smutting of both ears and grain.

*Summary*

A breeding programme having as its objective the incorporation of bunt resistance in three commercial Australian varieties of *Triticum vulgare* has been carried through to completion. The process of selection, checking, and rechecking of resistant segregates, together with the continued back-crossing to each of three recurrent parents is described.

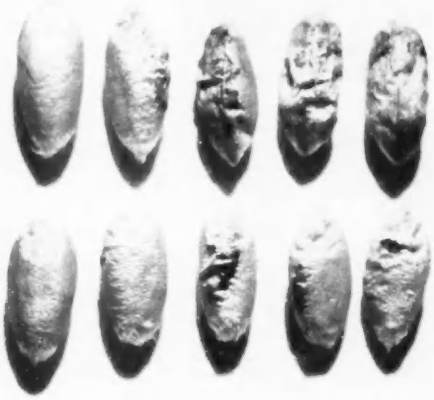
The resistance, derived in the first place from the tetraploid wheat Doubbi, has been shown to be conditioned by a single major gene tentatively designated 'd'.

Characteristic features of the incorporated resistance are, firstly, its effectiveness against five Australian 'races' of *Tilletia caries* and *T. foetida*, and, secondly, that the resistance not infrequently expresses itself as a partial smutting of both ears and grains of resistant plants.

REFERENCES

1. A. T. Pugsley, J. Aust. Inst. Agric. Sci., 1945, **11**, 28.
2. —— Empire J. Expt. Agric., 1949, **17**, 193.
3. —— and M. V. Carter, The resistance of twelve varieties of *Triticum vulgare* to *Erysiphe graminis tritici*. Aust. J. Biol. Sci. (In the press.)
4. F. N. Briggs and C. S. Holton, Agronomy J., 1950, **42**, 483.
5. C. S. Holton. Private communication, 1951 and 1952.
6. E. P. Baker, Inheritance of resistance to bunt, *Tilletia caries* (D.C.) Tul., in hybrids involving Turkey wheat selections 10095 and 10097. University of California thesis for Ph.D., 1949.
7. D. G. Smeltzer, Agronomy J., 1952, **44**, 529.

(*Received June 24, 1953*)



Two healthy and 8 partially bunted grains of R.D.R. 6189 × Ridley 48 × Ridley 48 × Ridley 48 × Ridley 48

# RECENT DEVELOPMENTS IN TICK CONTROL IN BRITAIN

DON R. ARTHUR

(*Department of Zoology, University of London, King's College*)

THE diseases caused by the common sheep tick (*Ixodes reduvius* = *Ixodes ricinus*) are, and have probably long been, responsible for a much higher proportion of the very high annual losses occurring in hill flocks in Britain than was previously suspected [1]. Lowland holdings in South Wales are also frequently infested with these ticks where they are responsible for redwater fever of cattle. The present account reviews the methods of control of *I. reduvius* attempted in Britain within the last decade or so. The arrival of DDT, BHC, and other chlorinated hydrocarbons for this purpose warrants also a consideration of their wider application against other ticks.

Destruction of the sheep tick may, theoretically at least, take place either by pasture treatment or by their elimination when the parasites are on the host. Large-scale pasture improvements on extensive hill and moorland grazings are impracticable [2] and any such improvement is feasible only in limited areas. Ticks brought in on sheep from already infected land to such improved (i.e. tick-cleared) areas would die because of the unsuitability of the now improved microhabitat. Such areas would, however, tend to be overgrazed by sheep and consequently become heavily infested with internal parasites [3]. On the other hand, where the pastures are little more than enclosed moorland (about 20 acres), land treatment presents a possible method of control.

A constant high relative humidity, such as provided by rank, matted vegetation, is necessary for the survival of the sheep tick. Removal of this 'mat' and the consequent modification of the microhabitat condition constitutes the basis of the experimental methods employed by Milne [3] in northern England and by Edwards and Arthur [4] in Pembrokeshire. Disking and harrowing breaks and loosens the matted turf and thereby permits increased aeration. These initial cultivations must be drastic [3, 4] to exercise any measure of control, and the growth of the better types of grasses and wild white clover should be encouraged. If ungrazed the experimental plots deteriorated after about 12 months, but grazing substantially reduced the rate of deterioration up to at least 4 years. Coincident with the reappearance of the 'mat' was an increase in the tick population.

Deep ploughing eliminated the rank vegetation layer resulting in temporarily improved herbage. Rushes rapidly reappeared in poorly drained pastures after such treatment with a recurrence of heavy tick infestations. On drier land the herbage, particularly if well managed, remained good for years and tick populations were correspondingly low. Differentiation between the values of the respective treatments was not possible, but in all drastic measures were necessary to reduce the populations of free-living sheep ticks [3, 4].

Cutting or mowing the herbage gave no relief from ticks: the number

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953.]

3988.84 Y

XUM

of ticks usually being greater than on untreated control plots [4]. Cut herbage provided a more level surface, thus permitting a closer contact between it and the collecting blanket during sampling [5] and the 'cut-herbage' plots hence yielded a higher proportion of active ticks than the unmown control plots.

Smith and Gouck [6] used DDT, both as a dust and as a spray, against ticks (*Ixodes ricinus scapularis*) when concentrated on vegetation alongside roads and paths frequented by this species. The dust was prepared by dissolving DDT (0·5–1 per cent.) in acetone and adding the solution to pyrophillite; in the spray 0·05–0·1 per cent. DDT was dissolved in pine oil with sodium monosulphate of monobutyldiphenyl as emulsifier. For 10–11 days after treatment, sprays (0·1 per cent. DDT) were as efficient as nicotine sulphate/sodium fluoride sprays, and the DDT dusts were as efficacious as derris dusts and sprays. DDT sprays (0·1 per cent. DDT) were superior to nicotine sulphate/sodium fluoride sprays and 1 per cent. DDT dust by the 21st–22nd day.

A pasture heavily infested with *Boophilus annulatus* in Florida was treated with 2 lb./acre of DDT by aeroplane by Blakslee and Bruce [7] and tick counts after 48 hours showed a 90 per cent. mortality.

In Britain, Heath [8] has experimented with DDT in the form of a dispersible powder, a miscible oil, and in solutions which were applied to pastures by means of a Todd insecticidal fog applicator. In these experiments much of the 'fog' drifted off the pasture, but no differences in tick populations were evident before and after treatment on known heavily-treated areas. The inconclusive nature of the results do, however, warrant further investigation.

Combinations of cultural practices with the application of DDT and BHC have been used in Pembrokeshire [4]. DDT (as a 5 per cent. dust) and BHC (0·26 per cent. gamma isomer) were dusted over plots which had previously been pitchpoled and disk-harrowed. Both DDT and BHC are toxic to unfed ticks and by forming a deposit over and in the interstices of the broken-down matted vegetation a greater area of the microhabitat was exposed to the action of the chemicals. Smith [9] has demonstrated that DDT and BHC persist in soils for a remarkably long time: after 18 months 95 per cent. DDT and 80–94 per cent. BHC can be recovered. Theoretically, therefore, a high mortality of unfed ticks could be expected. Plots treated in this way showed a pronounced improvement in the sward in the first season, but subsequently reverted to their original condition. Tick mortality was high, a condition which persisted for 4 years. Whether the residual effectiveness of the control measures was due to the drastic initial cultural processes or to chemical action is uncertain. But in view of the increase in the number of ticks consequent upon deterioration of the sward in other trials, it seems likely that chemical action was by no means negligible. No precise information is available as to the number of years that pastures treated in this manner will remain free of ticks when farm stock carrying ticks are allowed to graze such land. Nor have we information regarding the minimum concentrations of the active principles of DDT and BHC necessary to exercise control in this way.

*Chemical treatment of livestock.*—The control of arthropod ecto-parasites on domestic animals involves the application of chemicals to the body surface, which for greatest efficiency should destroy all external parasites. The arthropod parasites attacking livestock show diversity in their life-history and habits, and, moreover, a wide range of tolerance to pesticides. Hence, the ideal pesticide should produce a high initial kill of all feeding parasites and should have high residual toxicity, i.e. its effectiveness should be retained on the host's body for a reasonable period of time in accordance with farming practices. Moreover, it should be easy to prepare under the circumstances where it will be used, without hazard to operator or stock, and should be economical in cost.

In more recent years two trends in chemical treatment against ticks have been developed. The first lies in increasing the residual efficiency of arsenical salts, coal-tar derivatives, and derris preparations by the use of adjuvants and of combining two or more toxic products in a suitable formulation. The second, a sequel to the announcement by Wiesmann in 1942 that DDT (2,2-bis-(*p*-chlorophenyl)-1,1,1,-trichloroethane) used in certain concentrations was a new weapon in the control of agricultural pests, provided a stimulus for experimentation with this chemical in the control of ticks. This was succeeded in 1945 by similar claims for BHC (1,2,3,4,5,6-hexachlorocyclohexane).

*Arsenic.*—Field trials carried out by MacLeod [10] revealed that arsenic, either as thioarsenate (0·2 per cent. $As_2O_3$) or arsenite (0·16–0·2 per cent $As_2O_3$), killed attached ticks on sheep and gave good protection against reinfestation for 1–2 weeks. Similarly, feeding ticks on cattle were killed at these concentrations, but the residual effects were of short duration (3–5 days) and unreliable. This difference is probably correlated with the different texture of the body covering in these animals. The female sheep tick attaches itself on the sheep in marginal areas primarily where short open wool intermingles with the hair. This wool fleece retains soluble arsenic which is probably available in sufficient quantities to be toxic to ticks for some time after dipping. The hairy coat of cattle does not appear to have the same affinity for arsenic.

The subsequent developments in the arsenic field were in the direction of increasing the protective period of the dips. Increasing the bath strength is limited by the toxic action of the arsenic to the host. Experimental data show that there is no increase in protection against ticks (*I. reduvius*) with successive dippings through the cumulative action of the arsenic and that weaker concentrations of arsenic are desirable when frequent dipping is undertaken. In dipping a group of fifty sheep five times at fortnightly intervals in a bath concentration of 0·17 per cent. $As_2O_3$ and 0·125 per cent. cresols, MacLeod [10] found it necessary to reduce the strength by one-third to avoid damage to the sheep. This is also so in regular routine dipping. In South Africa, for example, cattle are dipped for certain ticks at 3-day intervals when concentrations of 0·1 per cent. $As_2O_3$ are employed; at dipping intervals of 5–7 days the concentration is increased to 0·2 per cent. $As_2O_3$ and at 14-day intervals to 0·3 per cent. $As_2O_3$. The efficacy of short-interval dipping, where agricultural practices permit it, has been attributed not only to the killing

of ticks already attached and feeding, but also to cutting down the number of potential egg-laying females.

To increase the effective duration of the arsenic it was incorporated in wool grease, a natural product of the sheep's skin and fleece, together with cresols [10]. The exact function of the cresols is doubtful; MacLeod [10] stated that it prevented the wool grease turning rancid, Milne [11] that it prevented the decomposition of the grease. Heath [8], on the other hand, expressed the opinion that it is unlikely that any one specific compound is required to prevent decomposition in an arsenical dip. Both MacLeod [10] and Milne [11] claimed that the addition of wool grease prolongs the toxicity of sodium arsenite but this contention is disputed by Heath [8]. The latter writer demonstrated that when a commercial dip containing wool grease and 0·22 per cent. $As_2O_3$ was tested against aqueous sodium arsenite (0·2 per cent. $As_2O_3$) both dips exerted a satisfactory kill and both gave the same measure of protection against tick reinfestation. The *in vitro* experiments of Whitnall and Bradford [12] with proprietary dips and sodium arsenite seemed to indicate a superiority of the latter over the former, as the integument absorbed more arsenic from aqueous sodium arsenite than from proprietary dips with the same arsenic content.

Some workers maintain that the action of arsenic on the tick is by contact [13], others that small quantities are ingested through the peripheral blood of the host and hence the arsenic acts as a stomach poison; yet others believe that arsenic kills by a combination of both methods. Whitnall and Bradford [12] demonstrated that when the body-contents of treated ticks were analysed separately from their integuments, more arsenic was found in the latter than in the former, suggesting the primary importance of the contact effects. This view was further supported by laboratory experiments when arsenic-sensitive and arsenic-resistant ticks were subjected to the same arsenical treatment. No arsenic was recovered from the integument of the arsenic-resistant strain which contrasted with the condition observed in the arsenic-sensitive strain.

The pioneering efforts of MacLeod [2] in the control of *I. reduvius* led to the production of a dip incorporating arsenic and derris which gave protection of a very high order during the first week or 10 days. The approximate formulation of MacLeod's dip when diluted ready for use was as follows (percentages): water 98·65, ground derris root 0·08, unsaponified wool grease, 0·73, saponified wool grease 0·09, tar oils and tar acids 0·26, arsenic 0·19, pH 8·43. The role played by the active constituents in this mixed dip is controversial. MacLeod [10] stated that wool grease did not increase the duration of effect of derris, which is effective for between 14–17 days even when the concentration of derris extract is increased from 0·05–0·1 per cent. This he attributed not to loss of derris but rather to chemical change of the active chemicals under weathering effects, sunlight, &c. Moreover, he contended that, because the effective duration of arsenic (0·2 per cent. $As_2O_3$) can be increased from 2 to 3 weeks when incorporated with wool grease, then the residual effects were due to the arsenic. Experimental work by Milne [11], using MacLeod's dip and two commercial dips containing arsenic,

cresols, and wool grease, showed that statistically significant differences between means of MacLeod's dip and the commercial dips were observed from 16–20 days, in favour of MacLeod's dip. The incorporation of derris, of the same order as in MacLeod's dip, into one of the commercial dips revealed no statistical difference in the means of treated sheep up to the 17th day. From this he justifiably presumed that the extended protective role devolves on the derris. He suggests that, from admittedly scanty data, the drainings from dipped sheep are robbed of an appreciable amount of derris (more as derris root than as liquid extract form). These 'drainings' might possibly increase the protection period afforded by derris, but MacLeod [10] wrote that 14–17 days appears to represent the maximum period of activity of derris, when present as a thin layer, at almost body-temperature and under the influence of light.

In 1951 Heath [8] treated a group of eighty sheep by dipping them in MacLeod's arsenic-derris dip and another eighty sheep in a commercial dip without derris. From the results of two reported trials he obtained the following results:

| | *Trial 1* | | *Trial 2* | | |
|---|---|---|---|---|---|
| | *Number of ticks on host after the following days* | | | | |
| | *14* | *21* | *7* | *13* | *18* |
| Commercial dip . . | 24·6 | 37·1 | 0·2 | 10·0 | 6·8 |
| MacLeod's dip . . | 32·0 | 28·7 | 0·1 | 10·1 | 7·0 |

In other words, on the basis of these results, MacLeod's dip did not show any appreciable advantage over the arsenical dip for protecting the sheep from reinfestation by the ticks.

As all three workers have had considerable experience in tick-control work the conflicting results and consequently their interpretations of the data are difficult to understand. If the addition of wool grease does not increase the effective duration of arsenic [8 10,] then there can be no purpose in using the arsenic-derris mixed dip, as both chemicals applied individually have a similar effective duration, i.e. about a fortnight. Milne's [11] data, on the other hand, show increased efficiency in the dips by the addition of derris: the commercial dips 'are more or less alike except' that MacLeod's dip contained derris root in addition. No precise information, however, is offered of the arsenic concentration in the commercial dips. Apart from vague generalizations no worker gave precise information on the prevailing weather conditions during the experiments, which may possibly be a contributory factor in accounting for the conflicting results obtained. The present position regarding the efficiency of the arsenical and incorporated products then seems obscure and a further review of the work seems necessary.

*Derris.*—Preliminary experiments showed that derris root had a marked killing effect against *Ixodes reduvius* (= *I. ricinus*), but the possibility of protective effects had not been fully investigated in the field until the work of Milne [11]. Previously Clunies Ross [14] had

observed that *I. holocyclus* is killed by a water suspension of the root and reinfestation is prevented for 3 days. In laboratory experiments [10], (*a*) derris was lethal to all stages of the tick at concentrations as low as 1 part of extract in 100,000 of water; (*b*) it intoxicated the tick during the actual immersion process; and (*c*) the time of immersion was important: thus immersion for ½ minute was less effective than immersion for 1 minute. In field trials an equal protective value is obtained both as an emulsion of extract and as a suspension of ground root, and at a concentration of 1 part of resin in 7,000 the effect is equal and comparable in its effective duration to sodium arsenite at a concentration of 0·16 per cent. $As_2O_3$. Milne [11] used derris powder for dusting sheep but noted in his experiments that blinding of the sheep occurred in late March and April, i.e. when sheep are at their poorest in condition. When the dusts were applied in May, i.e. when sheep are improved in condition, no blinding resulted. The use of dusts has the further disadvantage of taking a much longer time to apply to the individual sheep, and the powder may not go down to the skin as it does with the dip.

Two recent methods of controlling ticks on cattle by the use of derris preparations have been carried out [11, 15]. In Milne's preliminary experiments [11] the cattle were sprinkled with derris and fuller's earth powder which was rubbed in by hand, and cattle were also sprayed with a solution containing derris extract. The cattle remained free of ticks for 7–10 days and reinfestation was not complete for 3 weeks. The use of the powder was disagreeable for the operator and there was the ever-present risk of blindness to the cattle. Powder preparations on cattle present three further difficulties: (i) their inability to be retained on the skin for any length of time, especially in temperate oceanic climates; (ii) a high degree of waste during dusting; and (iii) the time taken up by dusting is prohibitive for the stockman. In later trials the derris and fuller's earth powder was made into a paste and proved equally effective; similarly a water suspension of ground derris root ½ lb. (without filler) in 1 gallon and incorporating soap as a wetting agent yielded comparable results. Arthur [15] used an aqueous suspension of 1 lb. derris (5·5 per cent. rotenone) with ¼ lb. soft soap in 1 gallon of water in the control of ticks on cattle. A very high mortality of attached ticks was noted within 2 days of derris-wash treatment, but the residual effects (i.e. when the number of ticks on the treated cattle exceeded 50 per cent. of those on the controls) varied in different trials from 9 to 21 days. The low residual toxicity in some trials was attributed to heavy rain reducing the efficacy of the wash, but the data, in general, confirm Milne's observations.

Aqueous suspensions of derris took a far heavier toll of ticks that had not started to feed within 24 hours of washing. The remaining ticks were either fully or nearly replete females and many of the latter dropped off the host before maturity: of the fully fed females which dropped off, a high proportion failed to lay eggs. In other words, the resistance of adult females, and indeed of all other stages, to derris preparations (Dr. G. Theiler, private communication) seems to be directly proportional to the quantity of blood which they have ingested.

Certain practical difficulties are, however, associated with derris washes on cattle. It has been repeatedly observed that the axillae and groin are the primary centres of reinfestation by ticks (*I. reduvius*) after washing with derris. Erosion of the derris particles is probably greater and more rapid in the groin, udder, and angles of the forelegs, because of the effects of rubbing during movement. Also, these are areas of low hair density in most breeds and probably during the initial wash they are unlikely to retain a high concentration of derris particles, such as is caught and retained by straining through the denser fleece of sheep. The greater efficiency of derris on sheep may possibly be due to this cause.

*Pyrethrum.*—Aqueous solutions of pyrethrum have a rapid knock-down of feeding ticks, being more toxic to newly attached individuals, but from experimental data collected in South Wales its residual effect seems to be negligible. On the other hand, pyrethrum is outstanding in its toxicity in both sprays and dusts against *Ornithodoros moubata* [16], but the powder should be of a high quality as it deteriorates rapidly under field conditions. As an acaricide its intrinsic value is limited because it is very readily destroyed by oxidation and by exposure to sunlight. When dissolved in mineral oils, however, pyrethrum keeps well. Further experiments are desirable to ascertain if, when in combination with another acaricide, its toxicity would be more effective and of longer duration.

*Chlorinated hydrocarbons.*—The second line of development has been the investigation of DDT, BHC, and other chlorinated hydrocarbons as acaricides. *In vitro* toxicity tests, carried out by Smith and Gouck in the United States and by Burtt [13] in Britain showed that DDT was efficient in killing ticks and its toxicity was maintained over long periods of time.

In controlling *Ixodes reduvius* on sheep in Britain, DDT at bath concentrations of 0·5 per cent. kept six sheep free of female ticks during the spring tick season, when they were dipped five times. In later experiments Heath [8] dipped sheep whenever he found female ticks which had fed for 5 days and showed no signs of imminent death. These DDT dips were so efficient that further dippings were necessary only on the 28th and 58th days after the initial dip. Moreover, it was observed that 1,061 fully fed ticks were found on undipped sheep, sixty-eight on sheep treated with a commercial arsenic dip (0·22 per cent. $As_2O_3$) and eight on DDT-treated sheep. Since fully fed females which succeed in engorging on DDT-treated sheep do not survive to lay eggs, DDT shows real promise as a 'tickicide'.

The same concentration of DDT, in an aqueous wash, killed newly attached ticks on cattle within 24 hours, and no ticks attached for a further period of 3 days, but within 12 to 15 days reinfestation by these parasites reached 50 per cent. of the control level [15]. A mixture of pyrethrum and DDT, used as a powder, likewise produced an immediate kill on ticks already feeding on cattle, but its value was low as a means of keeping cattle free of ticks for any length of time. Kaolin and talc have also been used as carriers for DDT, but the results are usually

unsatisfactory, a high degree of wastage occurs and where such preparations were retained on the skin they crusted badly and were very patchy.

Heath [8] found that BHC was about as effective as DDT for controlling the sheep tick on sheep in Britain, especially when used in similar emulsions and at the same concentrations.

Winter ticks (*Dermacentor albipictus*) on horses are effectively controlled either with 10 per cent. DDT powder or 1 per cent. DDT emulsion, which according to Knipling [17] gave protection from reinfestation for several weeks. The brown dog-tick, *Rhipicephalus sanguineus*, has also been eliminated from dogs with a 2 per cent. DDT emulsion and from premises by a 10 per cent. DDT powder. Whilst an increase in the DDT concentration to 5 per cent. kept dogs and calves free of both *R. sanguineus* and *Hyalomma mauritanicum* for 1 week, Sergent *et al.* [18] noted that it produced severe skin lesions. Wilson [19] controlled *R. appendiculatus* on cattle in Uganda by using ear sprays of 2·5 per cent. DDT and 0·325–0·65 per cent. BHC, but their residual toxicities were so low (4 days) as to necessitate applications twice weekly. A salve containing 5 per cent. DDT, dibutyl phthalate, and methyl abietate was found by Rude [20] to be efficacious in controlling *Amblyomma maculatum* (Gulf Coast tick) in the ears of sheep and cattle, but Blakslee *et al.* [21] found that spraying the whole animal with 2·3 per cent. DDT emulsion was even more effective. Suspensions of 0·25–1·0 per cent. DDT have proved successful against cattle ticks in the Argentine [22], and Wilkinson [23] has produced similar evidence in Uganda. The latter writer also contends that DDT emulsions were superior to dispersible powders.

All stages of the Lone Star tick (*Amblyomma americanum*), *A. maculatum*, *D. albipictus*, and the spinose ear tick (*Otobius megnini*) were killed by BHC (0·03–0·18 per cent. gamma isomer) regardless of the degree of engorgement of the tick. It failed, however, to give adequate protection against reinfestation and in comparative tests fully fed ticks were not killed by 1·5 per cent. DDT [17]. The more rapid killing of ticks by BHC than by DDT has been shown by Mackerras [24], who found that BHC (0·05 per cent. gamma isomer) had a higher and more rapid effect on *Boophilus annulatus microplus* than did emulsions of 0·35–0·55 per cent. DDT. Similarly Whitnall and Bradford [12] recorded that for arsenic-resistant ticks 1 per cent. DDT exercised a 60 per cent. control when compared with 100 per cent. control by 0·0029 per cent. gamma isomer of BHC.

The resistance of *Boophilus decoloratus* in South Africa to arsenic has been shown by Omer-Cooper and Whitnall [25], Du Toit *et al.* [26] and Whitnall and Bradford, and of *B. annulatus* in Australia by Hitchcock and Mackerras [27] and Mackerras [24]. Initially the South African arsenic-resistant tick was effectively controlled by BHC (gamma isomer 0·003 per cent.), but recently a BHC-resistant strain of this species has developed [28]. Chemical resistance appears to be an inherent character in these arachnids, for the South African areas which had arsenic-resistant ticks in 1939 still had them 10 years later despite dipping with

non-arsenical compounds. Arsenic-resistant and BHC-resistant ticks are always associated, but, whilst the immunity to arsenic developed over several years, that to BHC was accomplished in less than 2 years. Legg [29] reported that an arsenic-resistant strain of *B. annulatus* was killed by 0·25–0·5 per cent. DDT and that considerable residual effects were evident.

Tests carried out by the U.S. Bureau of Entomology and reported by Knipling [17], showed that Chlordane, at concentrations ranging from 0·25 to 1·5 per cent., gave complete or nearly complete control of unfed stages, and 0·5 to 1·5 per cent. concentrations nearly a complete kill of all stages of *Amblyomma americanum* on goats and cattle. DDT (1·5 per cent.) did not kill all the engorged forms. Moreover, at the same concentrations both Chlordane and DDT gave equal protection against reinfestation, i.e. about 2 weeks. Similar initial results were obtained against *Dermacentor albipictus*, the winter tick, but the residual toxicity of Chlordane at 0·5 and 0·75 per cent. prevented reinfestation for 2 months as compared with 1 month for DDT.

The same writer [17] records that at similar concentrations Toxaphene was superior to DDT, equal to Chlordane, but less effective than BHC in controlling fully fed ticks of *A. americanum*. Sprays of 0·5 per cent. Toxaphene controlled all developmental stages and gave a good protection against reinfestation for 2 weeks. A similar picture is given of the control of *Amblyomma maculatum*.

Knipling [17] also reported that Methoxychlor and TDE, both closely related to DDT in their chemical and physical properties, did not kill engorged ticks and on the whole were less effective than the other chlorinated hydrocarbon acaricides.

According to Lehman [30] quantities of the chemical are stored in the fatty tissue or else are passed out in the milk of dairy cattle when chlorinated hydrocarbon acaricides are applied to stock at the concentrations and frequency used for controlling ectoparasitic arthropods. The amount varies according to the acaricide used and for this reason the Bureau of Entomology and Plant Quarantine of the United States does not recommend their use on dairy stock. It may, however, be stated that BHC, for example, has been used at regular short intervals in South and East Africa, in Australia, and in South American countries for the last few years.

## REFERENCES


1. J. MacLeod, Empire J. Expt. Agric., 1939, **7**, 97.
2. —— Ann. Appl. Biol., 1941, **28**, 296.
3. A. Milne, ibid., 1948, **35**, 369.
4. E. E. Edwards and D. R. Arthur, Empire J. Expt. Agric., 1950, **18**, 119.
5. A. Milne, Ann. Appl. Biol., 1943, **30**, 240.
6. C. N. Smith and H. K. Gouck, J. Econ. Ent., 1944, **37**, 128.
7. B. Blakslee and W. G. Bruce, ibid., 1948, **41**, 104.
8. G. B. S. Heath, Parasitology, 1951, **41**, 209.
9. M. S. Smith, Nature, 1948, **161**, 246.
10. J. MacLeod, Ann. Appl. Biol., 1947, **34**, 207.
11. A. Milne, ibid., 1945, **32**, 128.
12. A. B. M. Whitnall and B. Bradford, Bull. Ent. Res., 1947, **38**, 353.
13. E. T. Burtt, Ann. Appl. Biol., 1945, **32**, 247.


XUM

14. I. Clunies Ross, J. Coun. Sci. Ind. Res. Aust., 1935, **8**, 8.
15. Don R. Arthur, Bull. Ent. Res., 1951, **41**, 555.
16. G. C. Robinson, ibid., 1944, **35**, 95.
17. E. F. Knipling, The New Insecticides for Controlling External Parasites of Livestock. U.S. Dept. Agric. E-762. Second Revision, 1951.
18. E. Sergent, A. Donatien, and L. Parrot, Arch. Inst. Pasteur Algérie, 1947, **23**, 249.
19. S. G. Wilson, Bull. Ent. Res., 1949, **39**, 269.
20. G. S. Rude, J. Econ. Ent., 1947, **40**, 301.
21. E. B. Blakslee, A. N. Tissott, W. G. Bruce, and D. A. Saunders, J. Econ. Ent., 1947, **40**, 664.
22. O. Baroni and R. Egli, Biológico (São Paulo), 1948, **14**, 109.
23. F. R. Wilkinson, East African Agric. J., 1948, **14**, 12.
24. I. M. Mackerras, Aust. Vet. J., 1947, **23**, 185.
25. J. Omer-Cooper and A. B. M. Whitnall, Nature, 1945, **156**, 450.
26. R. Du Toit, H. Graf, and P. M. Bekker, J. S. Afr. Med. Ass., 1941, **12**, 50.
27. L. F. Hitchcock and I. M. Mackerras, J. Coun. Sci. Ind. Res. Aust., 1947, **20**, 43.
28. A. B. M. Whitnall, J. A. Thorburn, W. M. McHardy, G. B. Whitehead, and F. Meerholz, Bull. Ent. Res., 1952, **43**, 51.
29. J. Legg, Vet. J., 1947, **23**, 181.
30. A. S. Lehman, Bull. Assoc. Food and Drug Officials, 1948, **12**, 82.

(*Received May 8, 1953*)

# FURTHER EXPERIMENTS ON WITCHWEED CONTROL

## I. THE EFFECT OF HORMONE WEED-KILLER APPLICATIONS AT DIFFERENT RATES AND TIMES ON IRRIGATED DURA[1]

K. WILSON JONES

(*Economic Botanist, Research Division, Ministry of Agriculture, Sudan Government*)

THE effects of applying the sodium salts of 2,4-D and MCPA to control Witchweed (*Striga hermonthecq* Benth.) have already been briefly described [1, 2]. Some anomalies came to light during these experiments, and the need to know more both of the mechanism of control and of the optimum strengths and times of weed-killer application led to the laying down of a large replicated experiment in season 1952–3 at the Gezira Research Farm.

Four fields, each of 5 feddans[2] gross area, were selected, giving as wide a range of infestations and fertilities as possible, viz.:

Field 45. Very heavily infested, medium fertility.
Field 77. Heavily infested, low fertility.
Fields 217 and 218. Lightly infested, good land, typical of central Gezira.

Five typical varieties of dura were selected for study, namely: Feterita, Mugud, Dwarf White Milo, Dwarf Higeiri, and Wad Fahl.

Rates of application of sodium 2,4-D were 0 (control), $\frac{1}{2}$, 1, and 2 lb. per feddan, using commercial material of 80 per cent. purity at $1\frac{1}{4}$ times these rates. Each of the strengths was applied on different sub-plots at 2, 3, 4, or 5 weeks after sowing, when the dura was approximately 6, 12, 18, or 24 in. high respectively.

*Experimental.*—Each of the four fields was divided into two blocks. A split-plot layout was used, with varieties occupying the whole plots and treatments the sub-plots. Each block therefore consisted of five whole plots, each divided into sixteen sub-plots providing for all combinations of strength and date of treatment. The land was prepared by ploughing and ridging before and during July 1952, and it was marked out immediately before sowing. The average net area harvested per sub-plot was 0·0245 feddan.

Sowing was carried out by hand, the normal method, on the ridges at 50 × 90 cm. spacing. Germination was uniformly good, about 90 per cent. of the holes showing emergence within 5 days. Resowing was carried out on August 4–6 to fill the gaps. The sprayings were done on August 10, August 17, August 25–26, and September 1; some disorganization was caused by inopportune rains which made the ground impassable for a day or so.

Since the principal effect on the Striga is believed to take place through the soil, it was considered that the concentration of the spray solution

[1] Dura = grain sorghum, *Sorghum vulgare* (L.) Pers.

[2] 1 feddan = 4,200 sq. metres = 1 acre approx. 1 rotl = 0·4494 kg. = 1 lb. approx.

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953.]

applied was not important, and for each sub-plot the requisite amount of chemical was dissolved in 2½ gallons of water, which was found sufficient to give a double coverage of the sub-plot without refilling. The volume per feddan was therefore 80 gallons approx., at strengths of 0·0625, 0·125, and 0·25 per cent. respectively.

*Observations.*—Damage to the dura became apparent 4 days after the first spraying, and at the same interval after the second spraying, but was not observed after the two later sprayings. The damage, where it occurred, became most marked about one week after the spraying. Two grades of damage were arbitrarily defined as follows:

Grade 1, Light damage. Leaves as though 'rolled up' in the lamina; stem and young leaves tending to burst through the distorted and partially unrolled leaf sheath.

Grade 2, Heavy damage. Leaves as above, but in addition the stem bent over, often with the tip actually pressing against the ground.

Grade 1 damage appeared to some extent in all treated sub-plots of the 2- and 3-week sprayings; Grade 2 was confined to the sub-plots treated at the higher strengths. Recovery from Grade 1 damage occurred after 2 weeks; that from Grade 2 took longer and in some cases did not occur. There were no significant varietal responses to the treatments, although the Higeiri variety seemed visually to be more affected than the others.

Death of the young dura plants ensued in some cases after the Grade 2 damage mentioned above, and as this cause had led to the abandonment of an experiment in 1951 [2] the damage was carefully studied. Plants with very heavy Grade 2 damage were strongly bent over after 1 week; those which did not show signs of recovery during the next week fell over with the base of the stem and roots exposed. Many of the young roots were dead, and the new adventitious roots produced higher up the stem were mostly unable to make contact with the soil. Many such affected plants, aided by the moist weather, finally re-established themselves and continued to grow from tillers; those which failed to re-establish contact with the soil were either desiccated or blown away by the wind.

The standard practice in experiments on the Gezira Research Farm differs from the normal practice in the surrounding commercial area, in that dura is always sown on well-made ploughed ridges. Among the tenants this is not so; dura is normally sown along the lines of the ridges remaining after the cotton of 2 years previously. This probably explains the differences found in 1951 between the Gezira Research Farm, where much of the dura was killed by the treatment, and Fatisa and Nuri, where no losses were recorded from this cause [2]. The soft new ridges rapidly subside under irrigation, falling away from the bases of the dura plants, and this process is assisted by rain running down the dura stems and washing soil into the furrows. The plants suffer some loss of roots as a result of the herbicide application, are unable to obtain support from the shallow soil around their bases, and fall over. Only a period of moist cloudy days can then enable the damaged plants to avoid desiccation and establish new roots. When sown on the flat, on

the other hand, the plants are well supported by the surrounding soil, and the new replacement roots can readily penetrate. A certain loss of stand is not important in terms of yield of dura grain provided it is well distributed through the plots, for dura is tolerant of very wide variations in spacing and sowing rate under irrigation.

Because of frequent and well-distributed rains, no irrigation was necessary until after all the sprayings had been carried out. Waterings were thereafter given fortnightly until harvest time. Differences in visible Striga between sub-plots became apparent by the eighth week after sowing. The first differences in the condition of certain varieties of dura were seen at about the same time, and became more marked as the season advanced.

### *Striga Observations*

One or two isolated Striga plants appeared above ground at about the time of the final spraying on September 1. The numbers of infested dura holes were counted on (1) September 7–10, (2) September 21–24, and (3) October 5–8.

Figures 1 and 2 show the build-up of infestation, as percentage of infested holes, during the course of the observations, and the effects of rates and times of treatment. The effects of both dates and strengths were highly significant at the second and third observations; the results of the first observations were not analysed because many sub-plots had no Striga.

Two weeks after the last count of infested holes, on October 19–23, all Striga plants were pulled by hand and weighed on the spot. Dry weight was not determined because the quantity was so great, but the rapid weighing would eliminate errors due to differential wilting in transit from the field.

TABLE 1. *Percentage of Dura Holes Infested with Striga on October 8*
(*Significant main effects and interaction*)

| *Varieties** | % | *Strengths*‡ *lb.* | % | *Dates*‡ *weeks* | % |
|---|---|---|---|---|---|
| Feterita . . . | 26 | 0 | 46 | 2 | 10 |
| Mugud . . . | 15 | ½ | 26 | 3 | 9 |
| Milo . . . . | 14 | 1 | 17 | 4 | 24 |
| Higeiri . . . | 20 | 2 | 12 | 5 | 26 |
| Wad Fahl . . . | 26 | .. | .. | .. | .. |
| L.S.D. . . . | 10 | L.S.D. | 7 | L.S.D. | 8 |

*Fields × strengths*‡

| *lb.* | *45* | *77* | *217* | *218* |
|---|---|---|---|---|
| 0 | 86 | 15 | 46 | 37 |
| ½ | 54 | 6 | 22 | 24 |
| 1 | 35 | 3 | 12 | 17 |
| 2 | 21 | 2 | 12 | 11 |

L.S.D. (within columns) 12

* Sig. at P = 0·05. ‡ Sig. at P = 0·001. L.S.D. = Least sig. diff. at P = 0·05.

*Percentage infestation.*—Table 1 shows the percentage of holes infested with Striga, as the significant main effects and interaction. The varieties Feterita and Wad Fahl were significantly more infested than were Mugud and Dwarf White Milo.

Increases in the rate of application of the weed-killer gave significant

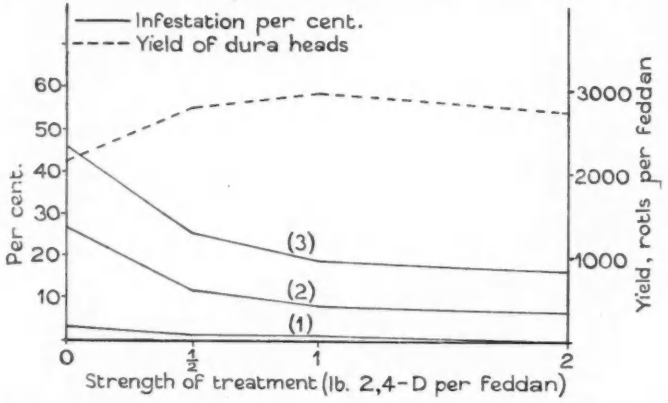



FIG. 1. Effect of strength of treatment on Striga infestation and dura yield.

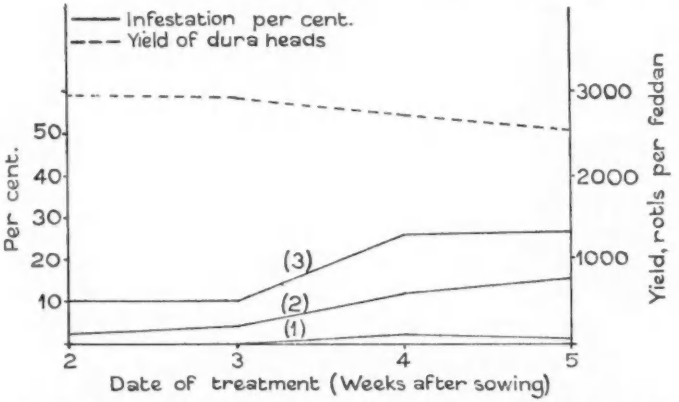



FIG. 2. Effect of date of treatment on Striga infestation and dura yield. (Numbers in brackets, in both figures, refer to date of observation given in text.)

overall reduction in infestation as far as the 1-lb. rate; the further reduction with the 2-lb. rate was not significant. Date of treatment, shown as 'very highly significant' in the analysis of variance, proved to have only one point of significant difference, separating the 2- and 3-week treatments from the 4- and 5-week treatments.

*Fresh weight of Striga plants.*—Results for the fresh weight of Striga plants pulled on October 19–23 were similar to those given by the counts

TABLE 2. *Weight of Fresh Striga Plants on October 23 (Rotls per feddan)*
(*Significant main effects and interactions*)

| *Strengths*‡ | | *Dates*‡ | | *Fields* × *strengths*‡ | | | | |
|---|---|---|---|---|---|---|---|---|
| *lb.* | | *weeks* | | *lb.* | *45* | *77* | *217* | *218* |
| 0 | 557 | 2 | 39 | 0 | 894 | 87 | 910 | 359 |
| ½ | 228 | 3 | 62 | ½ | 297 | 16 | 424 | 175 |
| 1 | 126 | 4 | 221 | 1 | 261 | 8 | 155 | 78 |
| 2 | 117 | 5 | 305 | 2 | 102 | 8 | 200 | 155 |
| L.S.D. | 10 | L.S.D. | 135 | L.S.D. (within columns) 359 | | | | |

| | *Varieties* × *strengths*† | | | | *Varieties* × *dates** | | | |
|---|---|---|---|---|---|---|---|---|
| | *lb.* | | | | *Weeks* | | | |
| | *0* | *½* | *1* | *2* | *2* | *3* | *4* | *5* |
| Feterita | 975 | 534 | 283 | 329 | 68 | 134 | 441 | 883 |
| Mugud | 334 | 202 | 36 | 94 | 11 | 35 | 185 | 210 |
| Milo | 249 | 76 | 41 | 26 | 12 | 26 | 74 | 78 |
| Higeiri | 267 | 82 | 124 | 28 | 26 | 29 | 165 | 93 |
| Wad Fahl | 962 | 247 | 145 | 108 | 80 | 89 | 239 | 260 |
| L.S.D. (within rows) 257, (within columns) 807 | | | | | L.S.D. (within rows) 297, (within columns) 975 | | | |

* Sig. at P = 0·05. † Sig. at P = 0·01. ‡ Sig. at P = 0·001.

of infested holes, as is shown by Table 2, which presents the significant main effects and interactions.

These two bases of measurement thus tell a consistent story of the Striga infestation. The effects of both the strengths and dates of spraying were highly significant, in general favouring a dose of 1 lb. per feddan of sodium 2,4-D applied at from 2 to 3 weeks after the crop is sown. The count of percentage of holes infested, which seems the more consistent measure, gave significant responses up to 2 lb. of treatment per feddan, on heavily infested land such as field 45.

Pot experiments carried out at the same time as the main experiment showed no Striga attachments on the roots of seedling dura at less than 2 weeks after sowing, whether the first watering took place a week before or at the same time as the sowing. Spraying the pots at the ½-lb.-per-feddan rate caused the death of these very small Striga seedlings within three days. The better effect of the early sprayings therefore seems to be due to the greater sensitiveness of the Striga during the first week or so of its life, and the subsequent growth of Striga on the early treated plots is mostly from seeds which have germinated after the breakdown of the chemical in the soil, whereas the heavier and earlier infestation that occurs on the later-treated plots is made up principally of actual survivors from the treatment.

### *Yield of Dura*

*Heads.*—Owing to the different rates of maturity of the varieties of dura under trial, harvesting was not carried out all at one time. In particular,

in accordance with normal Gezira practice, one extra watering had to be given to Mugud and Wad Fahl. Harvesting was done in the usual manner by hand-cutting the heads with about 2 in. of stalk, and filling into bags, which were then weighed. The heads were too numerous to count, and no weighings of threshed grain were made. The accepted factor for conversion of weight of fresh heads to weight of air-dry grain is 0·65. The dates of harvest were Higeiri, October 25–29; Milo, November 4–6; Feterita, November 8–9; Mugud and Wad Fahl, December 1–6.

Yields of heads per feddan are summarized in Table 3. The effects of all the four main factors attained significance, although as the fields were chosen from the first as contrasted types the difference between fields is not stressed. Three of the 2-factor interactions were also significant. Evidently the general recommendation as to strength of treatment on lightly-infested, normal Gezira land, should be 1 lb. per feddan; but

TABLE 3. *Weight of Dura Heads (Rotls per feddan)*

(*Significant main effects and interactions*)

| *Varieties*† | | *Strengths*‡ | | *Dates*‡ | |
|---|---|---|---|---|---|
| | | *lb.* | | *weeks* | |
| Feterita | 2,109 | 0 | 2,322 | 2 | 2,942 |
| Mugud | 2,839 | ½ | 2,774 | 3 | 2,913 |
| Milo | 2,794 | 1 | 2,864 | 4 | 2,766 |
| Higeiri | 2,605 | 2 | 2,746 | 5 | 2,554 |
| Wad Fahl | 3,036 | .. | .. | .. | .. |
| L.S.D. | 466 | L.S.D. | 135 | L.S.D. | 156 |

| *Fields* × *strengths*‡ | | | | | *Fields* × *dates*† | | | | |
|---|---|---|---|---|---|---|---|---|---|
| *lb.* | *45* | *77* | *217* | *218* | *Weeks* | *45* | *77* | *217* | *218* |
| 0 | 1,623 | 832 | 3,496 | 3,333 | 2 | 3,092 | 1,012 | 4,023 | 3,631 |
| ½ | 2,477 | 905 | 4,076 | 3,643 | 3 | 2,978 | 991 | 4,039 | 3,635 |
| 1 | 2,693 | 979 | 3,962 | 3,827 | 4 | 2,554 | 926 | 3,843 | 3,737 |
| 2 | 2,929 | 963 | 3,758 | 3,337 | 5 | 2,158 | 861 | 3,803 | 3,390 |
| L.S.D. (within columns) 268 | | | | | L.S.D. (within columns) 311. | | | | |

| *Varieties* × *strengths*‡ | | | | |
|---|---|---|---|---|
| | *lb.* | | | |
| | *0* | *½* | *1* | *2* |
| Feterita | 1,791 | 2,069 | 2,309 | 2,268 |
| Mugud | 2,432 | 2,799 | 3,174 | 2,950 |
| Milo | 2,864 | 2,921 | 2,778 | 2,611 |
| Higeiri | 2,472 | 2,783 | 2,591 | 2,574 |
| Wad Fahl | 2,044 | 3,301 | 3,472 | 3,325 |
| L.S.D. (within columns) 332, (within rows) 302. | | | | |

† Sig. at P = 0·01. ‡ Sig. at P = 0·001.

treatment up to 2 lb., although causing damage to the crop on lightly infested land, will nevertheless bring about an additional increase in yield on heavily infested land. As might be expected, the effect of the date of spraying was most apparent where there was most Striga.

The yield of Feterita was the lowest throughout; Milo, from being the best yielder on the control plots, dropped to third place under the best (1 lb.) rate of treatment, and Wad Fahl, from being next to the poorest yielder on the control plots, became significantly the best yielder under as little as the ½-lb. rate of treatment.

*Yield of straw.*—The average yields of straw obtained under the various treatments were erratic, and no significant differences other than varietal ones were observed.

## *Discussion*

Watt [3] was probably the first to attempt to control Striga by means of herbicides, using copper sulphate. Others, including Saunders [4], used sodium chlorate, but until the advent of the hormone-type herbicides, with their great selectivity, these applications mostly resulted either in failure to control the ravages of Striga or in the death of the crop. Attempts were made by Andrews [5] in the Sudan to kill the emerged Striga with a sulphuric acid spray, but crop yields were little improved. More recently, Martin [6] has reported a limited success against *Striga asiatica* (L.) Kuntze (= *S. lutea* Lour.) on maize in Rhodesia, by repeated sprayings of an MCPA formulation from the time of first emergence of the Striga seedlings until the end of the crop.

It has been shown by Saunders that during the time between the attachment of a *S. lutea* seedling to the crop root and the time of its emergence above ground, the seedling is accumulating its food reserves. There is a similar 'period of establishment' in the case of *S. hermontheca*. During this time it is inaccessible to any form of weeding, and during this time it is also preventing the host plant from establishing its own food reserves. If strict and continuous pulling of the aerial shoots of the Striga is then carried out, or if a contact weed-killer is applied which will destroy as much of the parasite as possible, the crop is still left in a weakened condition and cannot be expected to yield normally. The fact that in Martin's experiments repeated applications of herbicide had to be made, shows that it is improbable that he obtained more than a superficial kill of the parasites.

In this and previous work in the Sudan, the attempt has always been made to apply the hormone weed-killer as soon as the young crop is strong enough to tolerate the dosage required for control. Two weeks seems to be the limit of earliness for this; even so, some damage is caused to the crop at the higher strengths at this date, as can be seen from a study of the data from fields 217 and 218. The fact that in pot experiments no attachments of Striga to dura roots were formed before the second week after sowing the dura suggests that no advantage would be gained if earlier sprayings were possible. The present experiments indicate that there is little loss of control if the spraying is delayed as late as the third week after sowing. However, each week's delay after the third week

causes appreciable loss of crop, accompanied by a corresponding survival of Striga. Spraying appears to act in three ways:

(1) An immediate kill of the very tender and just-attached Striga seedlings.
(2) A period of unknown duration, of protection of the crop, either by killing the germinating Striga or by inhibiting its germination, which is due to weed-killer residue in the soil.
(3) Damage, of varying extent, to the well-grown Striga seedlings which were attached before treatment took place. Many of these will survive to bear flowers and damage the crop.

Spraying at the 2- and 3-week stages probably causes the first two types of effect, but later spraying, whilst killing some seedlings in this fashion, allows many of the parasites to survive. The total eradication of Striga might be attempted by using repeated weak sprayings at 2-week intervals, with the object of extending the postulated period of protection as long as possible.

Different varieties were included in the experiment to determine varietal differences in response to the weed-killer rather than to the Striga. It seems, however, that Dwarf White Milo has a very high degree of resistance to Striga and is well worth a trial where spraying treatments cannot be carried out. Mugud also shows a certain amount of resistance to Striga, and this is reflected in the rainland cultivations of the eastern Sudan, where more-favoured varieties are grown on the newly opened land, reverting to Mugud as soon as yields begin to fall off and Striga appears. The most striking fact regarding the varieties is the behaviour of Wad Fahl. This variety, a heavy yielder on good land, has given the best yield under all herbicide treatments, though without treatment its yield was next to the lowest recorded. The inclusion of field 77 in the trial showed that on exhausted land no improvement in yield is possible without remedy of the infertility either by manuring or resting.

*Summary.*—The hormone weed-killer 2,4-D was used in four field experiments on different types of land, infested in varying degree with *S. hermontheca* Benth. There were four levels of concentration applied on four different dates, to five varieties of dura (grain sorghum).

Significant increases in yield and decreases in infestation were found with increasing strengths of treatment. Significant decreases in yield and increases in infestation occurred if treatment was delayed beyond the third week after sowing the dura. All varieties of dura responded favourably to treatment on heavily infested land, but the effect was not significant with Dwarf White Milo, which shows some resistance to light infestation. The Wad Fahl variety gave the best response.

*Acknowledgements.*—The author wishes to acknowledge the great help given by the following: Mr. J. Taylor, Statistician, Research Division, for assistance with the experimental design; Dr. W. G. Templeman, for reading and correcting the proofs; and last, but not least, his technical assistant Mohd. Eff. Ibrahim and all his staff for their loyal and enthusiastic support.

## REFERENCES

1. F. W. Andrews and K. Wilson Jones. Annual Report for 1947–8, Research Div., Dept. Agric. and Forests, Sudan Govt.
2. K. Wilson Jones, Empire J. Expt. Agric., 1952, **20**, 78.
3. R. D. Watt, Transvaal Agric. J., 1909, p. 7.
4. A. R. Saunders, Studies in phanerogamic parasitism with particular reference to *Striga lutea* Lour., Union of S. Africa, Dept. Agric., 1933, Sci. Bull. No. 128.
5. F. W. Andrews, Ann. Appl. Biol., 1945, **32**, 3.
6. G. C. Martin, Rhodesia Tobacco J., 1951.

(*Received August 13, 1953*)

# SOME CHEMICAL ASPECTS OF 'BLACK-POD' DISEASE IN WEST AFRICAN AMELONADO CACAO

J. A. R. MACLEAN

(*West African Cacao Research Institute, Tafo, Gold Coast*)

THE chemistry of 'black-pod' disease of cacao does not appear to have attracted much attention, published work on Amelonado cacao being chiefly concerned with its incidence and control [1–5]. In some preliminary experiments on the butter-fat and free fatty acid content of healthy and 'black-pod' diseased beans, which were done in conjunction with the Chemistry section of the Nigerian Department of Agriculture, West [6] found that the fat percentage was slightly higher in diseased than in healthy beans, whilst the free fatty acid content was the same. The number of samples then examined was small and their classification appeared to be based on the external appearance of the pods, which could be misleading.

The purpose of the present investigation has been to determine the main chemical differences between healthy and 'black-pod' beans and, if possible, to suggest a use for the latter. Utilization of infected material is of importance in view of the high incidence of 'black-pod' disease in West Africa (Dade [1–4]; Gibberd, unpublished information).

*Procedure*.—Chemical analyses were done on beans from healthy and diseased pods borne on the same trees. Diseased material was obtained (*a*) from random harvesting in the field, and (*b*) by inoculation of fully developed healthy pods *in situ* with an aqueous spore suspension of *Phytophthora palmivora* Butl. followed by harvesting at regular intervals over a period of 2 months. Information using (*a*) is necessary as any collection of 'black-pods' from peasant farms might well be made by this method, which is based on external appearance of the pods, while (*b*) was considered the most suitable for relating degree of infection and chemical findings.

A necessary preliminary, however, was to determine whether any relationship exists between degree of infection of the beans and external appearance of the pods. This was done in the laboratory for convenience, by inoculating a series of forty fully developed Amelonado pods with an aqueous spore suspension of *P. palmivora*. The pods were stored at a relative humidity of 85–90 per cent., four pods being harvested at intervals of 10 days and the beans examined in longitudinal section under a microscope. The treatment was replicated three times.

Although the husks of all pods turned black within 14 days and the radicles in all beans were infected after 21 days, fungal infection was not present in all cotyledons until 32 to 36 days had elapsed from the date of inoculation. Repetition of this experiment (two replications) by inoculating pods *in situ* gave similar results, and it became clear that the external appearance of pods provided no guide to the degree of bean infection.

[Empire Journ. of Exper. Agric., Vol. 21, No. 84, 1953.]

XUM

*Analytical methods.—Fat* and *alkaloids* were estimated from the same sample by a combination of methods based on the separate procedures of Humphries [8, 9], and previously described [10].

*Free fatty acid.* The procedure outlined by Jamieson [11] was used. As the end-point is not sharp, a titration was not considered complete until the pink colour of the alcoholic solution was undischarged after shaking for 5 minutes and allowing to stand for a further 10. In some instances aqueous alcohol did not dissolve the fat completely; 10 ml. ether was then added before titration.

*Total nitrogen* was determined by the Kjeldahl method using 1 gm. of fresh beans, 30 ml. $H_2SO_4$ (conc.), and 5 gm. of a selenium catalyst, prepared by mixing 5 gm. selenium with 100 gm. $K_2SO_4$.

*Protein nitrogen* was determined by the same method using 2 gm. of fresh beans, 60 ml. $H_2SO_4$ (conc.), and 5 gm. of a selenium catalyst, the proteinaceous fraction having been obtained by the method of Jacob and Alten [12].

*Sugars.* 1-gm. samples of freshly harvested material were prepared for estimation by the procedure of Alten and Hille [13], and the reducing sugar and sucrose content of the extract was determined by the method of Hagedorn and Jensen [14, 15] with minor modifications. This method estimates: (A) per cent. reducing carbohydrates; (B) per cent. reducing substances after inversion; and (C) per cent. non-sugar reducing substances.

From these estimations:

$$\text{per cent. reducing sugars} = A - C.$$
$$\text{per cent. sucrose} = (B - A) \times 0{\cdot}95.$$

*Calculation of results.*—It should be noted that all results in the subsequent tables are calculated on the weight of *moisture-free, shell-free cotyledons* of unfermented beans unless otherwise stated, and all figures quoted in the discussion are also on this basis.

## *Experimental*

*Comparison of constituents of healthy and 'black-pod'-diseased beans from random sampling in the field.*—One diseased pod was harvested from each of forty trees on W.A.C.R.I. Old Station, from the 1949–50 and 1950–1 main crops, ripe healthy pods being harvested from the same trees for comparison. As it was not possible to establish a harvesting criterion from the external appearance of pods, beans were considered diseased for the purposes of the ensuing experiments if the radicles were infected and visible changes had taken place in the colour pigments of the cotyledons. Testas were removed and the beans dried at 100° C. for 20 hours before duplicate estimations were carried out. Results are summarized in Table 1, the alkaloidal percentages being calculated on the weight of dry, fat-free powder.

There was no significant difference in the fat content of the two categories of beans, although the percentage of free fatty acids in diseased

beans was very significantly higher; the alkaloids were significantly higher in healthy beans and the importance of this finding will be discussed later.

TABLE 1. *Means from Random Sampling in the Field*

| *Material* | *No. of estimations* | *% fat* | *% free fatty acid* | *% total alkaloids* | *% theobromine* | *% caffeine* |
|---|---|---|---|---|---|---|
| Healthy beans | 80 | 54·2±0·54 | 1·1±0·76 | 3·69*±0·05 | 3·41*±0·06 | 0·29*±0·01 |
| Diseased beans | 75 | 54·3 „ | 5·9‡ „ | 2·30 „ | 2·30 „ | 0·22 „ |
| Means | .. | .. | .. | 3·12 | 2·87 | 0·25 |
| L.S.D. (5%) | .. | .. | .. | ±0·135 | ±0·135 | ±0·026 |

* Sig. at P = 0·05. ‡ Sig. at P = 0·001.

*Tree-to-tree variation.*—This was considerable, as is indicated in Table 2.

TABLE 2. *Range of Composition, in Field Sampling*

| *Factor* | *Beans from healthy pods* | | | *Beans from diseased pods* | | | *S.E. of diff.* |
|---|---|---|---|---|---|---|---|
| | *Max. %* | *Min. %* | *Diff.* | *Max. %* | *Min. %* | *Diff.* | |
| Fat . . | 56·8 | 50·3 | 6·5 | 65·9§ | 45·2 | 20·7 | ±3·42 |
| Free fatty acids | 2·1 | 0·7 | 1·4 | 18·5 | 0·8 | 17·7‡ | ±4·31 |
| Total alkaloids | 4·14 | 2·76 | 1·38† | 4·83 | 1·29 | 3·54‡ | ±0·42 |
| Theobromine . | 3·92 | 2·56 | 1·36* | 4·24 | 1·10 | 3·14‡ | ±0·54 |
| Caffeine . . | 0·47 | 0·19 | 0·28‡ | 0·58 | 0·11 | 0·47‡ | ±0·08 |

* Sig. at P = 0·05. † Sig. at P = 0·01. ‡ Sig. at P = 0·001.
§ Beans in this sample were extremely desiccated.

*Inoculation of pods in the field with* P. palmivora.—Forty ripe Amelonado pods (four per tree) from the 1949–50 and 1950–1 main crops were inoculated at the apices with an aqueous spore suspension of *P. palmivora*, 4 pods being harvested at random 14 days after inoculation along with an equal number of healthy controls from the same tree, and thereafter harvest being made every 6 days. At each harvest the contents of the healthy and infected pods were bulked separately and the testas removed before grinding to a fine paste in a mortar. In samples where the degree of infection was advanced, the testas were removed by rubbing in wet sand and rinsing in distilled water. Sampling of the dried beans was done in duplicate. Five replications of the treatment were carried out in all and the results are summarized in the tables and figures which follow. In Table 4 the estimations were done on fresh material with the exception of those for alkaloidal nitrogen, which were done on dry, fat-free powder.

TABLE 3. *Means from Pods Inoculated in the Field: Fats and Alkaloids (Dry basis)*

| *Material* | *% fat* | *% free fatty acids* | *% total alkaloids* | *% theobromine* | *% caffeine* |
|---|---|---|---|---|---|
| Healthy beans (controls) . | 53·20 | 0·6 | 3·32 | 3·02 | 0·28 |
| Beans from pods infected *in situ* . . . . | 56·35* | 13·1‡ | 2·48 | 2·28 | 0·20 |
| S.E. . . . . | ±0·781 | ±3·52 | ±0·295 | ±0·302 | ±0·061 |

* Sig. at P = 0·05. ‡ Sig. at P = 0·001.

The results in Table 3 conformed, in the main, to those obtained from random sampling in the field although a greater degree of infection was apparently achieved by artificial inoculation in the field. This was reflected in the higher free fatty acid content of the diseased beans; on the other hand, the xanthine bases did not appear to decrease to the same extent as in random field sampling. A more detailed analysis of the nitrogenous constituents of the same samples of beans at varying degrees of infection, and also of those substances most likely to be affected by fungal attack, namely, the sugars, produced the results in Table 4.

TABLE 4. *Means from Pods Inoculated in the Field: Sugars and Nitrogen (Fresh basis)*

| *Material* | *% reducing sugars* | *% sucrose* | *% total N* | *% protein N* | *% alkaloidal N (calc. as theobromine)* |
|---|---|---|---|---|---|
| Healthy beans (controls). | 0·1 | 2·4‡ | 2·3 | 1·6 | 0·5 |
| Beans from pods inoculated *in situ*. . . | 0·3 | 0·9 | 2·1 | 1·5 | 0·4 |
| S.E. . . . | ±0·10 | ±0·10 | ±0·06 | ±0·03 | ±0·03 |

‡ Sig. at P = 0·001.

The figures for reducing sugars showed a wide variation and the amounts present were very small. The result of greatest interest is the fall in the alkaloidal nitrogen in the beans from pods infected in the field, the difference just failing to reach significance (the variance ratio, F = 5·97, a significant effect requiring F = 5·99).

There was considerable variation in the degree of infection of pods in the various harvests throughout a replication, which was reflected in the determinations of bean constituents and is indicated in Figs. 1 and 2. These are based on the mean values for the various constituents from replicated field inoculation experiments.

### *Incidence of 'Black-Pod' Disease in the Gold Coast and Nigeria*

Accurate assessment of the incidence of 'black-pod' over extensive areas is difficult as a satisfactory survey necessitates regular inspection

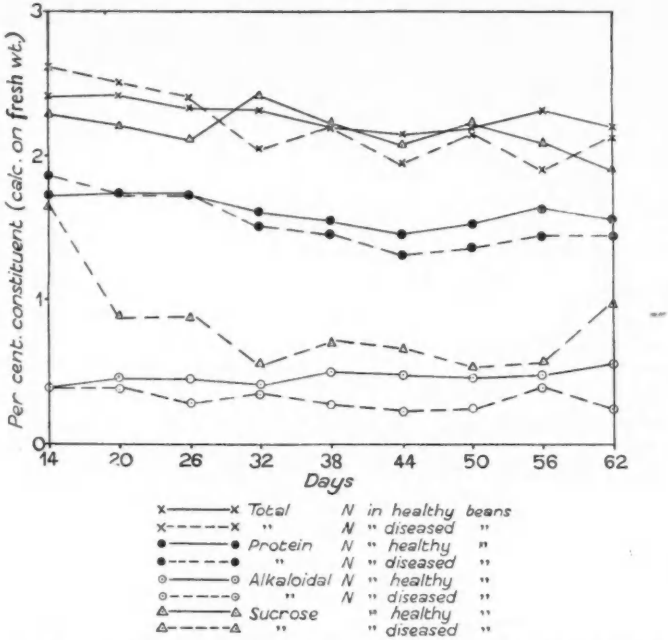

Per cent. constituent (calc. on fresh wt.)
Days
Total N in healthy beans
" N " diseased "
Protein N " healthy "
" N " diseased "
Alkaloidal N " healthy "
" N " diseased "
Sucrose " healthy "
" " diseased "

FIG. 1. Fluctuation in the content of sucrose and various forms of nitrogen with time.

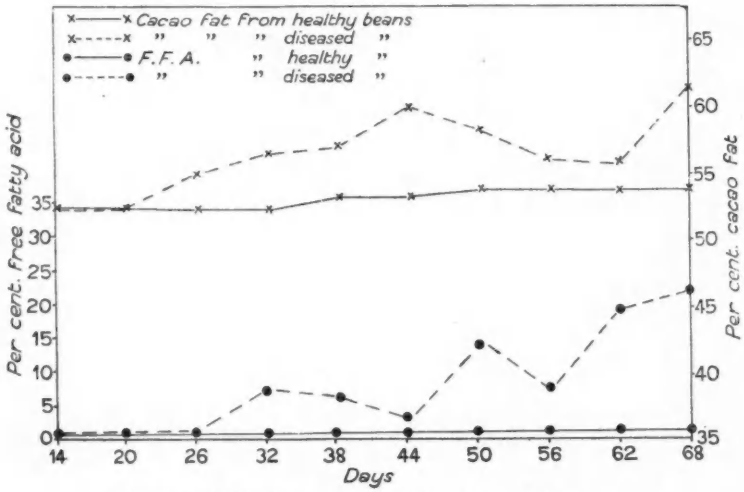



FIG. 2. Variation in cacao fat and free fatty acid with time.

of the same areas at short intervals throughout the cropping season [1–4]. Incidence figures for the cacao-growing areas in the Gold Coast and Nigeria, for example, are mostly intelligent guesses based in the main on records from small experimental plots, and it is important to bear this in mind when considering their implications.

In the Gold Coast the work of Dade [1–4] is the chief and almost the sole reference source. At Anyinam, situated in the Birim valley, where conditions for the development of 'black-pod' are highly favourable, experimental plots in 1926 showed an incidence of *c.* 40 per cent. of the total trunk-borne crop; the proportion which had to be discarded as unfit for fermentation was not given. At Tafo, Owen [16] has shown that the proportion of 'black-pods' which had to be discarded on eight scattered plots totalling 1 acre during the 1949–50 season was 9·7 per cent. Observations on the same plots during the 1950–1 and 1951–2 seasons indicated discard figures of 5·2 per cent. in both seasons, despite weekly harvesting during the periods when a heavy crop was offering and three-weekly harvesting at other times (unpublished information).

In Nigeria, the position can best be summarized by quoting the information in Table 5 (for which I am much indebted to Mr. A. V. Gibberd, then Assistant Director of Agriculture, Western Provinces, Ibadan).

TABLE 5. *Losses from 'Black-Pod' Disease in Nigeria*

| *Province* | *Percentage of total Nigerian production (approx.)* | *Estimated per cent. loss from 'black-pod'* | |
|---|---|---|---|
| | | *In an average year* | *In bad years* |
| Oyo . . | 55 | 10 | 25 |
| Ondo . | 22 | 30 | 60 |
| Abeokuta } Ijebu } | 20 | 5 | 10 |
| Benin . | 3 | 1 | 5 |

The average production for the Western Provinces is *c.* 100,000 tons, so that the figures in Table 5 represent a fluctuation in crop losses between 13,000 and 30,000 tons of dried fermented cacao per annum. For the reasons just quoted [1–4] it must be emphasized that these figures are only approximate; attention is drawn to them here in order to give some indication of the scale of annual loss.

## *Discussion*

It is necessary to emphasize at the outset that the quantitative changes in the various chemical constituents of healthy and 'black-pod' diseased beans, which are reported in this paper, are not necessarily caused by *P. palmivora*. The testas and dried mucilage of beans, both in naturally infected pods and in those inoculated in the field with spore suspensions of *P. palmivora*, were found to harbour a number of saprophytic fungi including *Botryodiplodia theobromae*, *Ceratostomella paradoxa*, and

species of *Aspergillus*, *Mucor*, *Fusarium*, *Penicillium*, and *Cephalosporium*. The identity of those which penetrate the cotyledons has not been established but it is clear that fungi other than *P. palmivora* are likely to influence such chemical alterations as are described.

The findings of West [6] have been substantiated in part. The maintenance of the fat content in infected beans at the same level as that of healthy beans, or a relatively higher one, may mean that the fungi invading the cotyledons do not attack this constituent or that they are capable of elaborating a fat which is not normal cacao fat but is extractable by the usual fat solvents. The latter possibility is suggested by the appearance of the fat from samples of infected beans after reducing the free fatty acid content to less than 1 per cent. by distillation *in vacuo*. The resulting fat was brown in colour and had a wide range between incipient fusion and complete melting (which occurred at 39° C.). It is possible that alkali refining may be a more suitable method for the treatment of 'black-pod' cacao fat than distillation *in vacuo*. A more striking difference between cacao fat from healthy and 'black-pod' beans concerns the free fatty acid content, which varies according to the degree of infection; in naturally occurring infections individual results varied between 1 per cent. and *c.* 20 per cent., whilst beans from some artificially inoculated pods in the field gave results as high as 34 per cent. Results quoted by the Chemistry section of the Department of Agriculture, Nigeria [6] indicating no change in the percentage of free fatty acids, were probably due to the non-infection of the beans examined, although the pod husk showed the characteristic symptoms of 'black-pod' disease. (For the fungal mycelia to permeate the cotyledons of all beans in pods artificially infected in the field takes more than 30 days.)

The result of most interest is the significant fall in the alkaloidal content of the bean, and more particularly in the theobromine. This was observed in the random field sampling, and in pods inoculated *in situ* the difference just failed to reach significance. This difference was associated in all experiments with consistent results for both total and protein nitrogen. The consistency of the protein nitrogen figures might be due to the fact that (*a*) cotyledon protein, and (*b*) protein breakdown products plus fungal mycelia were not estimated separately, but this does not explain the accompanying fall in the alkaloidal nitrogen calculated as theobromine. Theobromine was considered by Knapp and Wadsworth [17] to exist in the cacao bean either as the free base or as an easily decomposable compound, and Fincke [18] stated that the base is possibly present as theobromine tannate. In whatever form it is present, the theobromine appears to be utilized as a source of nitrogen by the fungi present in the cotyledons in preference to other forms of available nitrogen. Growth of fungi, not specifically identified, from 'black-pod' beans, comparable with that obtained when using cassava extract containing 0·4 per cent. N based on dry weight, was obtained on cassava starch-dextrose-agar media variously buffered between 6·0 and 7·5, containing an equivalent amount of nitrogen in the form of theobromine.

There was little difference in the reducing-sugar content of healthy and diseased beans; the figure (*c.* 0·1 per cent., based on fresh material) was the mean of 100 samples, and was only one-third that found by Knapp [19] for West African cacao. On only two occasions was the figure of 0·3 per cent. reached. The sucrose content of diseased beans was markedly lower 3 weeks after inoculation of healthy pods with *P. palmivora* (see Fig. 1) than was that of the healthy controls. The sucrose figure for healthy beans (2·4±0·1 per cent.) was obtained from a wide range of samples, and it is difficult to reconcile this finding with the absence of sucrose in cacao beans recorded by Knapp [19]. Analysis of the sugars in the cotyledons by paper chromatography indicates that only sucrose is present in fresh beans; in fermented beans sucrose is completely converted to invert sugar (R. V. Wadsworth, private communication).

From the estimates of 'black-pod' incidence in the major cacao-producing territories in West Africa it is clear that this disease causes a considerable annual loss in saleable crop. Figures for the Tafo observation plots over the three-year period 1949–51 (incl.) showed that nearly 7 per cent. of the total harvest had to be discarded through 'black-pod', even with one- to three-weekly harvesting of infected pods. A higher incidence can be expected on peasant farms where the crop is generally harvested at much greater intervals and little or no removal of 'black-pod' is practised.

It is generally assumed that the incidence of 'black-pod' in the Gold Coast is not so high as in Nigeria. If the percentage of the Gold Coast crop discarded because of 'black-pod' is based on the conservative figures obtained at Tafo, the annual loss in dry fermented cacao is still likely to be as great as in Nigeria, in a comparison of average years. Accurate comparison is difficult, however, as the proportion of 'black-pod'-infected cacao, which cannot be legitimately used for fermentation but may still be utilizable in other ways, is not known in either territory; the proportion will depend mainly on the relationship between the development of the crop and the time of infection.

Two products of commercial value are likely to accrue from the diseased material; namely, cacao butter from beans of mature (and some immature) pods and theobromine from the dry, fat-free residue. Problems posed by the composition of 'black-pod' fat, for example, its behaviour on storage and the most suitable method of removing the high free fatty acid content that is likely to be present, can only be resolved by processing quantities which can be handled on a commercial scale (in this instance not less than 1 ton). Discards, other than 'black-pods', which would certainly be present in any large-scale harvest of infected pods, would also have an effect. From such tests the suitability of the fat for use in chocolate manufacture could be assessed. Work on a similar scale is also necessary before deciding whether theobromine extraction (where yield rather than purity is the critical factor) from this source is economic. The amounts obtained by the laboratory method described earlier and from a wide range of samples were invariably over 2 per cent.

Other products from diseased material are likely to be of less importance. Analysis of six samples of fat-free powder from diseased beans and of the same number from diseased husks indicated pentosan contents which were equivalent to $2{\cdot}2 \pm 0{\cdot}07$ per cent. and $4{\cdot}3 \pm 0{\cdot}21$ per cent. furfural respectively; these proportions are not sufficient to warrant further work.

*Summary.*—A comparison was made of the quantitative changes in various constituents of healthy and 'black-pod' beans, obtained from (*a*) random harvesting in the field, and (*b*) pods inoculated *in situ* with a spore suspension of *Phytophthora palmivora* Butl.

Cacao fat was not affected in quantity but there was an appreciable rise in the free fatty acid content of fat from diseased beans.

There was a significant fall in the percentage of theobromine in diseased beans from pods sampled at random in the field. The content, however, was still greater than 2 per cent. (based on fat-free, shell-free beans). Total and protein nitrogen in both healthy and 'black-pod' beans remained remarkably constant.

Sucrose was recorded as the main sugar in healthy beans; the content was significantly lowered in 'black-pod' beans.

The extent of the losses caused by 'black-pod', and the possible utilization of diseased beans, are briefly discussed.

*Acknowledgements.*—Thanks are due to Dr. S. P. Wiltshire, Director of the Commonwealth Mycological Institute, Kew, and Mr. A. L. Wharton, W.A.C.R.I., for identification of fungi, to Mr. R. Knight for sub-culture work, and to Messrs. S. K. Ayertey, B. Bentum, and S. K. Dzewu for careful routine analyses. The author is indebted to Mr. R. V. Wadsworth of Cadbury Bros. Ltd. for general advice, and to the Director of Cacao Research, W.A.C.R.I., for his interest in this work and for permission to publish.

## REFERENCES

1. H. A. Dade, Economic Significance of Cacao Pod Diseases, &c. Gold Coast Dept. Agric. Bull., 1927, No. 6, p. 7.
2. —— The Relation between Diseased Cushions and the Seasonal Outbreak of 'Black-Pod' Disease of Cacao. Ibid., 1928, No. 13, p. 85.
3. —— Further notes on Cushion Canker of Cacao. Ibid., 1929, No. 16, p. 135.
4. —— The Determination of the Incidence of 'Black-Pod' Disease of Cacao. Ibid., 1930, No. 23, p. 122.
5. J. West, 'Black-Pod' of Cacao—Experimental Control on Native Farms. Nigerian Dept. Agric. Bull., 1936, No. 11, p. 55.
6. —— Bull. Imp. Inst., 1943, **41**, 234.
7. Anon., West African Cacao Res. Inst., Ann. Rep. 1948–9, 49.
8. E. C. Humphries, Biochemistry of Cacao. 4. A Note on the Estimation of Fat in Cacao. Eighth Ann. Rep. on Cacao Res. (Trinidad), 1938, 39.
9. —— Biochemistry of Cacao. 2. A New Method for Estimating Total Alkaloids in Cacao. Ibid., 1938, 36.
10. Anon., West African Cacao Res. Inst., Ann. Rep., 1948–9, 43.
11. G. S. Jamieson, Vegetable Fats and Oils. Reinhold Pub. Corp. (2nd ed.), 1953, 437.
12. A. Jacob and F. Alten. Arbeiten über Kalidüngung, Dritte Reihe. Verlagsges. für Ackerbau, G.M.B.H. Berlin, 1942, 87.
13. F. Alten and E. Hille, Bodenk. u. PflErnähr., 1938, **9/10**, 696.

14. H. C. HAGEDORN and B. N. JENSEN, Biochem. Z., 1923, **135**, 46.
15. ——, ibid. **137**, 93.
16. H. OWEN, Ann. Appl. Biol., 1951, **38**, 715.
17. A. W. KNAPP and R. V. WADSWORTH, J. Soc. Chem. Indust., 1924, **43**, 124 T.
18. H. FINCKE, Z. Unters. Lebensm. 1928, **56**, 312.
19. A. W. KNAPP, Cacao Fermentation. John Bale, Sons and Curnow Ltd., 1937, 78.

(*Received September 2, 1953*)

# AUTHOR INDEX


Arthur, Don R., recent developments in tick control in Britain, 321–30.
Asker, A. A., *see* Ragab, M. T.
Bailey, G. L., fodder-beet. III. Feeding trials with cattle, 42–48.
Barclay, C., self-cleaning, miniature thresher, 190–2.
Barrowman, J. R., castration of lambs: comparison of techniques, 193–203.
Beckley, V. R. S., *see* Pereira, H. C.
Boaz, T. G., *see* Barrowman, J. R.
Bolton, J. L., breeding alfalfa in Canada, 241–54.
Bonsma, J. C., climatological research on animal husbandry, 154–75.
Burnett, G. S., *see* Robinson, K. L.
Carey, T. M., manuring of sugar-cane, 99–115.
Castle, M. E., *see* Bailey, G. L.
Clinton, P. K. S., *see* Gibson, I. A. S.
Coey, W. E., *see* Robinson, K. L.
Constable, D. H., manuring of *Hevea* in Ceylon, 131–6.
Cormack, M. W., *see* Bolton, J. L.
Davidson, T. M. W., clonal variation and yield in potatoes, 137–40.
Dowson, W. J., *see* Wiehe, P. O.
Foot, A. S., *see* Bailey, G. L.
Gibson, I. A. S., pre-emergence seed-bed losses in groundnuts, 226–35.
Hafez, E. S. E., conception-rate and periodicity in the buffalo, 15–21.
Hafez, E. S. E., puberty in female farm animals, 217–22.
Hattingh, E. R., observations on ecology of *Steobe vulgaris*, 309–13.
Hauser, Georg F., sugar-beet cultivation in Afghanistan, 283–8.
Haylett, D. G., *see* Theron, J. J.
Hodnett, G. E., sugar-cane responses to fertilizers in Trinidad, 204–16.
Hodnett, G. E., *see* Constable, D. H.
Hofmeyr, J. H., *see* Bonsma, J. C.
Jones, K. Wilson, witchweed control. I. Hormone weed-killers, 331–9.
Kadi, M. R., *see* Ragab, H. T.
Koncar, L., wool fineness of lambs, 61–64.
Lawley, D. N., *see* Davidson, T. M. W.
MacLean, J. A. R., chemical aspects of 'black-pod' cacao disease, 340–9.
Mahedevan, P., production statistics of Sinhala cattle, 55–60.
Marle, J. van, *see* Bonsma, J. C.
Milton, W. E. J., herbage palatability on undeveloped grasslands, 116–22.
Motta, M. S., *Panicum maximum*, 33–41.
Mundy, H. G., arable farming problems in Southern Rhodesia, 123–30.
Nye, P. H., value of fertilizers in the Gold Coast. I. Methods, 176–183. II. Soils of the far north, 262–74.
Pande, H. K., effects of weeding on wheat yield, 297–303.
Pereira, H. C., grass establishment on eroded soil, 1–14.
Pugsley, A. T., back-crossing wheat for bunt resistance, 314–20.
Ragab, M. T., factors affecting weights of Ossimi lambs, 304–8.
Robinson, K. L., responses of pigs to dietary penicillin, 275–82.
Robinson, P., *see* Carey, T. M.
Russell, T. A., spacing of Nigerian cacao, 145–53.
Sheffield, F. M. L., virus diseases of sweet potato in Africa, 184–9.
Shepherd, R. W., mechanical thinning of sugar-beet, 236–40.
Smalcelj, I., *see* Koncar, L.
Soper, M. H. R., farm practice and the productivity of field beans, 22–32.
Spedding, C. R. W., effect of sub-clinical worm-burden on lambs, 255–61.
Speyer, F. C. O., reflections on the world nitrogen position, 49–54.
Theron, J. J., regeneration of humus under a grass ley, 86–98.
Thomson, L. B., the P.F.R.A. and a new prairie agriculture, 289–96.
Towers, K. G., *see* Barrowman, J. R.
Vine, H., maintenance of soil fertility in Nigeria, 65–85.
Wiehe, P. O., bacterial disease of cassava in Nyasaland, 141–3.
Wilson Jones, K., *see* Jones, K. Wilson.


# SUBJECT INDEX


Agriculture, prairie, the P.F.R.A. and new, 289–96; conservation of soil and water resources in Alberta and Saskatchewan, 289–95; irrigation, major projects, 293–5; pastures, community, on abandoned land, 292–3; permanent agriculture developed, 289–93; Prairie Farm Rehabilitation Act (P.F.R.A.) and agricultural improvement in western Canada, 289 sqq.; soil drifting and soil moisture, 289–1; special projects in British Columbia and Manitoba, 294–5; strip cropping, 290; water development, 291.

Alfalfa, breeding in Canada, 241–54; cold resistance, 242; disease resistance, 243–4, 246–7; drought tolerance, 244; isolation plots and cages, 247–8; organization of projects, 241–2; selection methods, 245–6; special screening and breeding techniques, 246–52; synthetic combinations based on progeny performance, 251–2; winter hardiness, 242.

Animal husbandry, climatological research on: beef-cattle in South Africa, 154–75; adaptability in different breeds, 157 sqq.; adjustment to semi-arid sub-tropical

environment, 167–70; body-temperature reaction and heat tolerance, 161–3; characteristics of cattle suited to dry, warm conditions, 171–4; comparison of Africander, British, and cross-bred cattle, 157 sqq.; fertility, 159–64; mortality rates, 165–8; weight changes, 160–3.

Animals, farm, puberty in female, 217–25; age and weight at puberty, 218–22; sheep, rabbits, and poultry in Egypt, puberty in, 218 sqq.; species, breed and individual differences observed, 218–24.

Beans, field, influence of farm practice on productivity, 22–32; bird damage, 29–30; fertilizing and manuring, 24–26; pests and diseases, 29–30; rate and method of sowing, 27–28; seed quality, 28–29; sowing date, 26–27.

Beef-cattle production in colonial territories: *see* Animal husbandry, climatological research on.

Buffalo, Egyptian dairy, conception-rate and periodicity in, 15–21; breeding efficiency and conception-rate, 16–17, 18–20, oestrous cycle length, 17–18; silent heat, 17, 20.

Bunt, resistance of wheat to, *see* Wheat, back-crossing of.

Cacao, Amelonado, some chemical aspects of 'black-pod' disease in, 340–9; alkaloids (theobromine, &c.) and nitrogen content of healthy and diseased beans, 342–3, 346; changes in composition with time, 343–4; fat and free fatty acid content, 341–3, 346; incidence of 'black-pod' disease in Gold Coast and Nigeria, 343–5; sugars in healthy and diseased beans, 343, 347; utilization of diseased beans, 347–8.

Cacao, Nigerian, spacing of, 145–53; farmers' planting method, 151; peasant farms, 149–51; trial begun in 1934, 145–7; trial begun in 1942, 148–9; value of close planting and closed canopy, 152–3.

Cassava, a bacterial disease of, in Nyasaland, 141–3; description of pathogen (*Xanthomonas cassava* sp. nov.), 142–3; leaf-spot and defoliation resulting from, 141.

Cattle, beef-; *see* Animal husbandry.

Cattle, Sinhala, of Ceylon: general life and production statistics, 55–60; breeding, 56–57; calving, lactation and dry-period statistics, 56; heritability of milk yield, 59; milk production 57–59.

Dura (sorghum), witchweed in, *see* Witchweed (*Striga hermontheca*), control of.

Farming, arable, in Southern Rhodesia, some problems of, 123–30; compost, 126; dung, value of, 125, 127; grass leys and legumes, 128–9; green manuring, 125 sqq.; nitrogen and phosphate problems, 129–30; soil fertility maintenance, 125; soil organic matter, 126–7.

Fertilizers, survey of the value of, in Gold Coast food-farming areas. I. Aims and methods, 176–183; conditions in the areas, 176–9; field experiment methods used, 178–82; organization of experiments, 182. II. Granitic soils of the far north, 262–74; cash return from fertilizers, 270–2; cereals and groundnuts, results with, 264 sqq.; climate, soils, and agriculture; 262–4; fertilizer recommendations, 272–3; nitrogen and phosphate, responses to, 264 sqq.; organic manuring, effects of, 266–7.

Fodder-beet. III. Feeding trials with dairy cattle, 42–48; composition of fodder-beet and other feeds, 44; cows, dairy, direct feeding trials, 42–43; mangolds, comparison with fodder-beet, 43–48.

Grass establishment on eroded soil in Kenya, 1–14; carrying capacity of experimental pastures, 7–9; conservation of soil moisture, 10–11; establishment of grasses with soil-conserving cultivation methods, 5–8; labour expenditure, 12–13; overgrazing, and potential carrying capacity, 2–3; soil erosion, severity of, 1–2; soil restoration methods used, 3–4; soil structure studies, 11–12.

Grass ley, *see* Soil humus, regeneration of.

Grasslands, undeveloped, in Wales: palatability of herbage, 116–22; grasses, herbs and other species, discussion of, 120–1; palatability, relative, of species on open hill grazings, 117–20; season, influence of, 117–21.

Groundnuts, pre-emergence seed-bed losses of, in Tanganyika, 226–35; fungi as a cause of pre-emergence loss, 229–32; mechanical injury to seed, 226–9; Rhizopus spp., chief cause of loss, 230–2; seed-treatment with fungicides, effect of, 232–5.

Guinea grass, *see Panicum maximum*.

*Hevea brasiliensis*, manuring of, in Ceylon, 131–6; girth of trees, fertilizer effects on, 132; nitrogen, phosphate and potash responses and interactions, 132–5; phosphate, importance of, 132–4; yield of rubber, fertilizer effects on, 133 sqq.

Lambs, castration of, comparison of techniques, 193–203; crushing (the Burdizzo instrument), 195; physical effects on lambs, 196–7; rubber-ring ligature (Elastrator), 195–6; subsequent performance of lambs, 197–9.

Lambs, Ossimi, factors affecting weights of, 304–8; genetic correlations between weights, 306–7; heritability of birth, weaning, and marketing weights, 305 sqq.; phenotypic correlations, 305–6.

Lambs, sub-clinical worm-burden of, effect on liveweight gain, 255–61; faeces consistency, food intake, and egg-counts: effects of dosing with worm larvae, 259–60; *Trichostrongylus axei*, effects on liveweight changes, &c., of dosing with larvae of, 256 sqq.

Lambs, wool of, fineness and medullate fibres in, 61–64; age and region of lamb, relation of fibre thickness to, 61 sqq.; relation of medullated fibres to, 63–64; Yugoslavia, properties of wool of cross-bred lambs in, 61 sqq.

Lucerne, *see* Alfalfa, breeding in Canada.

Nitrogen, reflections on the world position

of, 49–54; future trends in demand for agricultural nitrogen, 50 sqq.; population and cropped area of world, in relation to potential nitrogen consumption, 52 sqq.; potential nitrogen in A.D. 2000, 53–54; present production and consumption of fertilizer nitrogen, 49–50.

*Panicum maximum*, 33–41; distribution of Guinea grass in tropical countries, 33; establishment, 35; management, utilization and conservation, 35–37; nutritional status, 39–40; strains and ecotypes, 32–34; yields and responses to fertilizers, 37–39.

Pigs, response of, to dietary procaine penicillin, 275–82; appetite, effect of penicillin on, 276, 278–9; feeding trials with weanling and fattening pigs, 276–8; food utilization, 277, 279; maximum response, time of, 276–81; recession due to discontinuance of penicillin, 277; weight-gains, effect of penicillin on, 277 sqq.

Potato, sweet, virus diseases of, in Africa, 184–9; distribution in tropical Africa, 184–5, 187–9; other conditions resembling virus disease, 186; spread of virus, 187–9; symptoms of virus disease in sweet potato, 185–6.

Potatoes, evidence of clonal variation affecting yield of, 137–40; clones of King Edward variety, yields of, 138–9; yield differences between clones, significant and heritable, 138 sqq.

Rubber, manuring of, *see Hevea brasiliensis*.

Soil fertility, experiments on the maintenance of, in Nigeria, 65–85; burning mucuna (green manure), effect on fertility, 73–83; fallows, vegetative, restoration by, 83, 84; fertilizer (nitrogen and phosphate) experiments and results, 76–79; green manure, use of in fertility maintenance, 68 sqq.; mucuna (velvet bean) as main green manure crop, 69–84; soil analyses, 81–83.

Soil humus, regeneration of, under a grass ley, 86–91; fertilizer (nitrogen and phosphate) responses, as hay yields, 87–88; hay and protein production in relation to soil humus, 91–96; nitrogenous fertilizers, use of to increase humus formation, 91–97; Rhodes grass ley in South Africa, experiment with, 86 sqq.

*Stoebe vulgaris*, observations on the ecology of, 309–13; control of Stoebe by heavy grazing with increased fertility, 311 sqq.; distribution of *Stoebe vulgaris* (*Slangbos*) in S. Africa, 329–11; management, effects of, 311–12; mowing or burning relatively ineffective, 311; role of Stoebe in succession, 311; soil fertility, effect of, 312–3.

*Striga hermontheca*, *see* Witchweed.

Sugar-beet cultivation and improvement in Afghanistan, 283–8; comparison of native and improved cultivation methods, 285–7; native cultivation method described, 284; sowing in rows on flat soil, success of, 286 sqq.

Sugar-beet, mechanical thinning of, 236–40; conditions for success with mechanical thinning, 238 sqq.; cross-blocking, trials with, 236–8; precision drills, 237–8; rubbed seed, 237–8.

Sugar-cane, manuring of, 99–115; Commonwealth territories included in survey, 99; designs and numbers of field experiments used, 99; fertilizer (nitrogen, phosphate, and potash) effects on cane yield, 105–11; liming responses, 114–15; nitrogen responses, 105–8; organic manures (pen and green manures, molasses), 111–14; response curves and optimal dressings, 101–5; sugar content, fertilizer effects on, 100–1.

Sugar-cane, responses to fertilizers in Trinidad, 204–16; designs of experiments and conversion of results, 206–9; molasses and filter-press mud, effects of, 213–14; nitrogen responses, 209–10; pen manure, effects of, 212–13; phosphate responses 210–11; potash responses, 211–12; sugar content, fertilizer effects on, 213–14.

Sweet potatoes, *see* Potato, sweet.

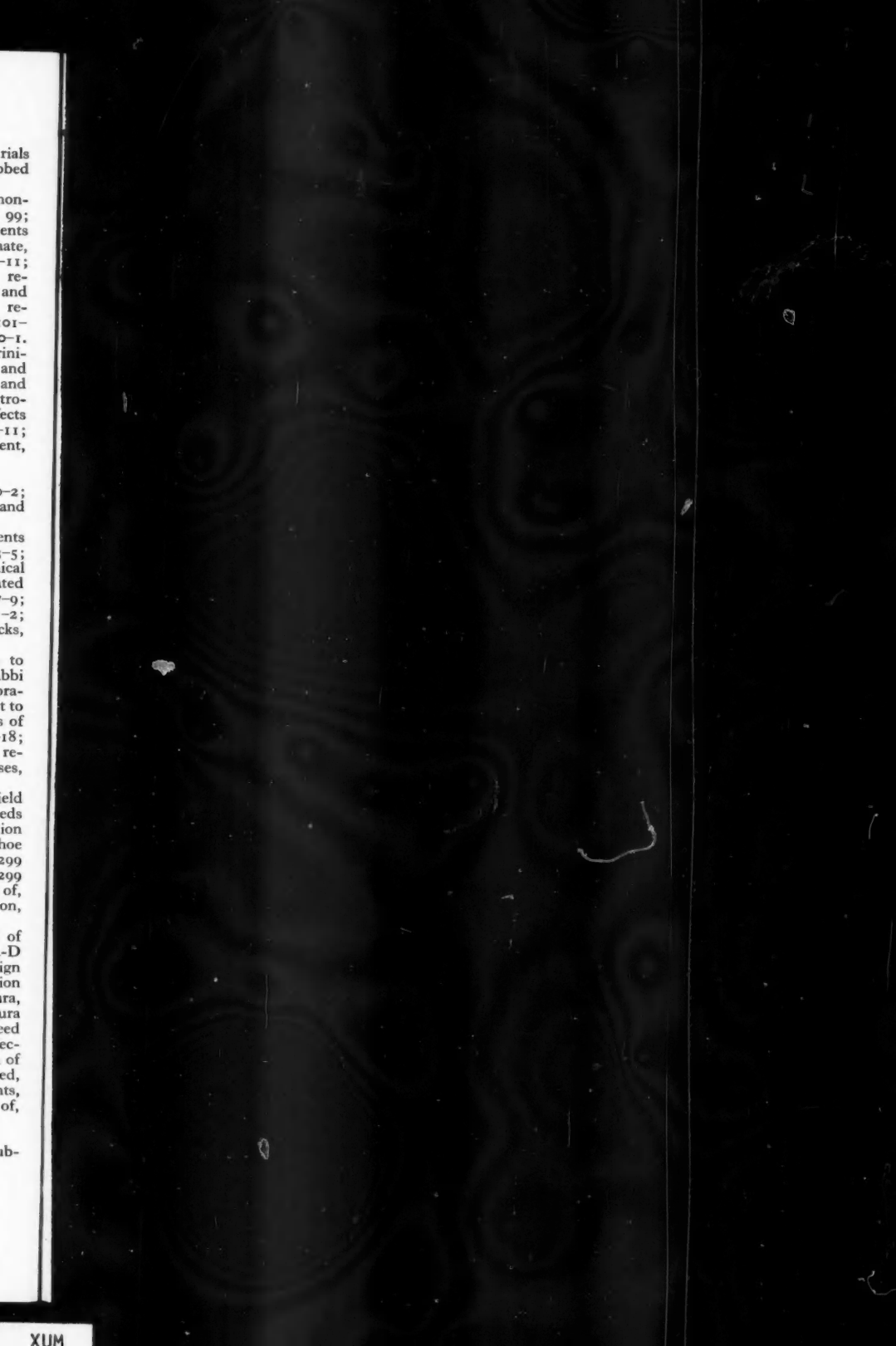
Thresher, miniature, a self-cleaning, 190–2; corn and peas, threshing single ears and pods, 190 sqq.

Tick control in Britain, recent developments in, 321–30; arsenic for tick control, 323–5; cattle ticks, control of, 322 sqq.; chemical treatment of livestock, 323 sqq.; chlorinated hydrocarbons (BHC, DDT, &c.), 327–9; cultural practices for tick control, 321–2; derris and pyrethrum, 325–7; sheep ticks, control of, 321 sqq.

Wheat, back-crossing of, for resistance to bunt in South Australia, 314–20; Doubbi tetraploid wheat, resistance and incorporation of, 314–15; genes in wheat resistant to 'races' of bunt, 319–20; Insignia series of crosses, 315–17; Javelin series, 317–18; Ranee-Doubbi selections as basis of resistance, 314 sqq.; Ridley series of crosses, 318–19.

Wheat, weeding, in India, effect on the yield of, 297–303; density, relative, of weeds and wheat, 298; fertility of soil, interaction with effect of weeding, 302–3; hand-hoe and hand-pulling, comparison of, 299 sqq.; tillering, effect of weeding on, 299 sqq.; weed species, names and density of, 298; yield of grain, effect of weeding on, 298 sqq.

Witchweed (*Striga hermontheca*), control of by hormone weed-killers, 331–9; 2,4-D for witchweed control in Sudan, design and results of experiments, 331 sqq.; action of 2,4-D on Striga, 336–8; damage to dura, extent of and recovery from, 332–3; dura (sorghum), irrigated, control of witchweed in, 331 sqq.; dura varieties, relation to effectiveness of weed-killer, 333–8; strength of weed-killer, effects on dura and witchweed, 332–7; Striga observations and weights, 333–5; time of application, importance of, 333–8.

Wool, fineness of, *see* Lambs, wool of.

Worm-burden, sub-clinical, *see* Lambs, sub-clinical worm-burden of.